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MECHANICAL PROPERTIES OF HIGH-TEMPERATURE FIBROUS STRUCTURAL MATERIALS

Part II — Fabric Tensile Properties at Elevated Temperatures in Vacuum

W. D. Freeston, Jr.
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Fabric Research Laboratories, Inc.

TECHNICAL REPORT AFML-TR-67-267, PART II

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Air Force Materials Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433

NOTICES

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FOREWORD

This report was prepared by Fabric Research Laboratories, Inc., under U. S. Government Contract No. AF 33(615)-2457. This contract was initiated under Project 7320, "Fibrous Materials for Decelerators and Structures," Task 732002, "Fibrous Structural Materials." The work was administered under the direction of the Nonmetallic Materials Division, Air Force Materials Laboratory, Research and Technology Division, with Messrs. J. H. Ross and S. Schulman acting as project engineer.

This report covers work conducted from March 1965 to June 1967.

The program was directed by Dr. W. D. Freeston, Jr. The tensile testing in vacuum was carried out by Mr. D. S. Johnstone.

The authors wish to express their gratitute to Mrs. M. M. Schoppee and Mrs. J. H. Davis for assisting with the testing and the report preparation and Dr. M. M. Platt for handling contractual matters, making numerous suggestions during the course of the program and reviewing the report.

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This technical report has been reviewed and is approved.

J. H. Ross

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ABSTRACT

The tensile properties of fabric woven from nylon, Dacron, Nomex, polybenzimidazole, graphite, Fiberglas and Chromel R were determined in vacuum at 70°F after vacuum exposures of 1 to 64 hours. The tensile properties of the fabrics were also determined at elevated temperatures in vacuum and the data compared to the fabric properties in air.

Vacuum exposures (to 1×10^{-6} torr) of 1 to 64 hours appear to have only a small effect on the tensile properties of polymeric fabrics. Over a broad temperature range polymeric and metal fabrics also exhibit roughly the same tensile properties in vacuum as in air. Fiberglas fabric exhibits up to 45% greater tensile strength in vacuum than in air.

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SUMMARY

A. INTRODUCTION

Fabrics have played an important role in every aerospace vehicle flown to date and it is anticipated that they will continue to be an essential material in future space exploration and sophisticated new military systems. The successful utilization of fabrics in these applications depends on the ability of the materials to retain their standard performance characteristics under extreme environments. However, insufficient information on the properties of fabrics woven from the candidate high-performance fibers is available at the present time to accurately estimate their full potential for these new systems.

B. PROGRAM OBJECTIVE AND SCOPE

The objective of this program was the determination of the tensile properties of fabrics woven from the various available high-performance fibers at ambient and elevated temperatures in vacuum. Fabrics woven from nylon, Dacron,* Nomex,* polybenzimidazole, graphite, Fiberglas,** and Chromel R† were included in the investigations. The tensile properties of the fabrics were determined in vacuum after vacuum exposures of 1 to 64 hours. The tensile properties of the fabrics were also determined at elevated temperatures in vacuum and the data compared to the fabric properties in air.

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*Manufactured by E. I. du Pont de Nemours & Co., Wilmington, Delaware.

**Manufactured by Owens Corning Fiberglas Co., Toledo, Ohio.

†Manufactured by Hoskins Manufacturing Co., Detroit, Michigan.

C. CONCLUSIONS

Vacuum appears to have only a small effect on the breaking strength of polymeric fabrics. The nylon, Dacron, Nomex and polybenzimidazole fabrics evaluated exhibit tensile strengths in vacuum within approximately $\pm 5\%$ of their strength at standard conditions - 14.7 psi, 70°F, 65% RH air. However vacuum has a more significant effect on the rupture elongation and tensile modulus of the fabrics; in general, the rupture elongation decreases and the modulus increases. Dacron fabric exhibits only a small change in rupture elongation - from -1.3% to +2.7%; the other fabrics exhibit as much as a 20% decrease in elongation.

Increasing the length of exposure to vacuum from 1 to 64 hours has little effect on fabric tensile properties with the exception of the modulus of the nylon fabric which increases with increasing time in vacuum.

Both heat-cleaned and greige Fiberglas fabric exhibit up to 45% greater tensile strengths in vacuum. The rupture elongation and tensile modulus of glass fabric are also larger in vacuum.

The tensile strength of nylon fabric is approximately the same in air and vacuum at temperatures to 300°F. However, the fabric strength is much larger in vacuum than in air at 400 and 450°F. The fabric strength in vacuum at 450°F is about 40% and at 475°F, 5% of the strength at standard conditions. The fabric rupture elongation is approximately the same in vacuum and air to 200°F and much higher in vacuum at higher temperatures. At 400°F the fabric rupture elongation is 17% in air and 52% in vacuum, and at 450°F, approximately 5% in air and 39% in vacuum. The modulus of the fabric is approximately the same in air and vacuum throughout the temperature range. The fabric modulus at 450°F in vacuum is about 17% of the value exhibited at standard conditions.

Dacron fabric exhibits approximately the same tensile strength in air and vacuum to about 400°F and approximately 50% greater strength in air at 475°F. The fabric strength at 475°F in vacuum is about 25% of its strength

at standard conditions. The rupture elongation of the fabric is moderately greater in vacuum at the elevated temperatures and the fabric modulus is approximately the same in both environments throughout the temperature range. The rupture elongation at 475°F in vacuum is about 131% and the modulus 64% of their respective values measured at standard conditions.

The tensile properties of Nomex fabric are approximately the same in vacuum as in air at ambient and elevated temperatures. The strength exhibited by the fabric at 750°F in vacuum is approximately 13% of its strength at ambient conditions; the rupture elongation at 750°F is 61% and the modulus, 9% of the ambient values.

The tensile strength of the PBI fabric is the same in vacuum and air at ambient and elevated temperatures. The fabric strength at 700°F in vacuum is approximately 50% and at 800°F, 14% of the values exhibited at standard conditions. The rupture elongation of the PBI fabric is also the same in both environments to about 700°F. However, at 800°F the elongation is 3.8% in air and 78% in vacuum. The fabric modulus is approximately the same in air and vacuum to 700°F; the modulus in air is about seven times the value in vacuum at 800°F.

Although only a limited amount of data was obtained, it appears that the tensile strength, rupture elongation and modulus of heat-cleaned Fiberglas fabric are considerably larger in vacuum than in air at ambient and elevated temperatures. The fabric strength at 1200°F in vacuum is approximately 15% of its tensile strength at standard conditions and 10% of its 70°F strength in vacuum.

It appears that the tensile properties of multifilament yarn, fine-wire fabric are approximately the same in vacuum as in air to about 1250°F. At 1500°F the fabric exhibits approximately the same percent strength retention in both environments but considerably more elongation in vacuum – 24.5-29.8% in vacuum compared to 10.9% in air. However, at 1750 to 2000°F the tensile strength and modulus of the fabric are smaller and the rupture elongation many times larger in vacuum. At 1750°F in vacuum the fabric exhibits

approximately 13% of its strength at standard conditions and at 2000°F, 7%; at 1750°F in air the fabric exhibits 18-1/2% strength retention and at 2000°F, 15%. The fabric rupture elongation at 1750°F is 20.0% in vacuum and 5.8% in air and at 2000°F, 16.8% in vacuum and 1.3% in air.

D. RECOMMENDATIONS FOR FUTURE RESEARCH

Since low temperatures are encountered in outer space and on the moon's surface, the tensile properties of the various types of fabrics being used in aerospace systems should also be determined at subambient temperatures in vacuum.

The properties of textile structures after long-term vacuum exposures are also of interest, particularly the tensile properties of critically loaded aerodynamic decelerator components which are deployed after atmospheric re-entry. Long-term vacuum exposures of these items will purge them of water vapor and other volatile materials which are stable in a standard atmosphere; return to a terrestial environment will result in moisture regain and temperature and pressure equilibration. Therefore, there is a need to measure the tensile properties of fibrous structures after a long time in vacuum (at cryogenic, ambient and elevated temperatures) followed by air pressurization as a function of time in vacuum, vacuum temperature, time from initiation of the repressurization cycle, and the repressurization atmosphere (temperature, relative humidity).

The only means by which a body can exchange heat with its surroundings in the vacuum of outer space is by radiation. Therefore, the emissivity of the various candidate fabrics should be determined over a broad temperature range in vacuum. The transmission and reflectivity of the fabrics should also be measured.

An improved method should be developed for clamping glass and carbon/graphite fabric test specimens for tensile testing at elevated temperatures in air and vacuum. Subsequently, glass fabric and fabric woven from carbon yarn and from high-modulus graphite yarn should be evaluated at ambient and elevated temperatures in air and in vacuum using the improved clamping technique.

SECTION II

HIGH-TEMPERATURE, HIGH-VACUUM TENSILE TESTING FACILITY

To determine the tensile properties of a series of fabrics of current interest, a high-temperature, high-vacuum tensile testing furnace* was installed in a floor-model Instron tensile test machine (see Figure 1).[4] The unit used is equipped with a 15 CFM** mechanical roughing pump, a 4-inch oil diffusion pump with cold cap and a right-angle, cold-finger type LN_2† trap. There is a combination hot-filament ionization gauge and a two-station thermocouple gauge for determining the vacuum. Pressures on the 10^{-7} scale have been achieved with no sample in the chamber.

In order to achieve pressures on the low side of the 10^{-6} torr range the cold trap must be filled with liquid nitrogen. One filling lasts about 7 hours. In order to be able to keep the chamber at low pressures throughout over-night exposures, an LN_2 liquid level controller was installed.

The furnace is equipped with tantalum heating elements and shields. The test chamber is 2-1/2 inches in diameter and 8 inches long; the region of uniform temperature is approximately 6 inches long. Temperatures in the chamber are measured with thermocouples. A potentiometer-type temperature controller and silicon-controlled rectifier allow setting and automatic maintenance of the desired temperature. Temperatures to 3000°F have been achieved.

The oven temperature does not control well automatically at temperatures below about 500°F when a thermocouple protruding into the center of the chamber is used as the sensor. However using a thermocouple bonded to the heating element as the sensor for the temperature controller overcomes this problem.

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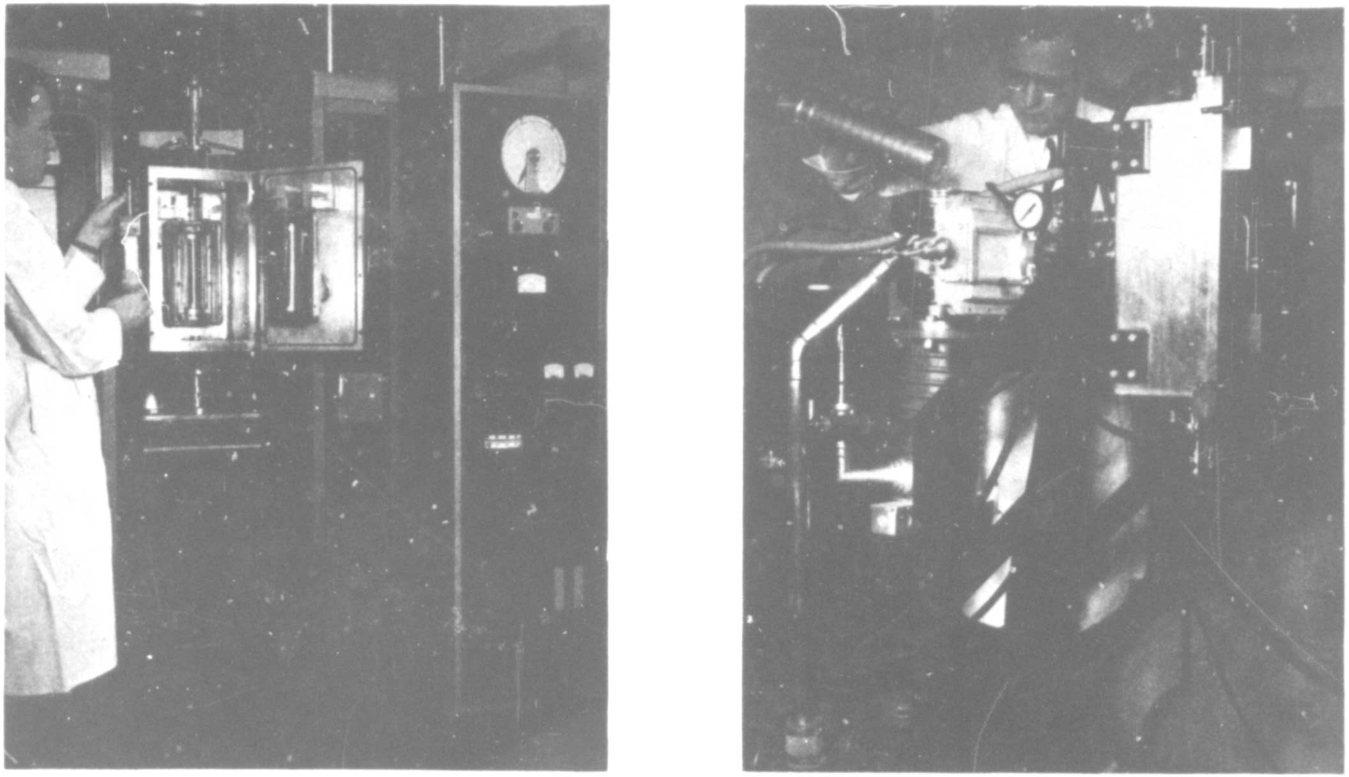
*Manufactured by Centorr Associates, Inc., Suncook, New Hampshire.

**Cubic feet/minute.

†Liquid nitrogen.



(A)   (B)

FIGURE 1. HIGH-TEMPERATURE, HIGH-VACUUM TENSILE TESTING FURNACE.

The temperature readings are checked by monitoring the output of the thermocouples with a precision potentiometer.

Provision has been made in the vacuum furnace for inert gas operation. Pump and heat zone controls are electrically cascaded and interlocked to insure proper operating sequence. Flow switches are provided in cooling water lines to protect furnace and user against improper use or sudden loss of water. A separate over-temperature limit instrument has been incorporated to protect against exceeding a specific set-point. A vacuum interlock is also provided; when the pressure rises above full scale on any scale of the hot-filament ionization gauge, power to the heaters is shut off.

The jaws in which the fabric test specimens are clamped connect to the Instron through the furnace wall by means of a rod-and-bellows seal. However, the effect of the bellows on measured loads is negligible. The spring constant of the top bellows is less than 1 lb/inch and the deflection of an Instron load cell, less than 0.010 inch per 1,000 lbs of applied load. Therefore, all loads measured in the vacuum furnace are only in error by roughly 0.01 lbs per 1000 lbs of measured load, an insignificant amount.

As shown in Figure 1, the vacuum furnace is mounted on a dolly. This allows the unit to be rolled into and out of the Instron with a minimum of effort. When in place, the chamber is rigidly connected to the Instron frame with eight bolts, thus insuring that accurate alignment of the chamber in the Instron is achieved every time. The alignment is occasionally checked by rigidly connecting the two bellows assemblies together with a bar; replacing the Instron load cell with a disk, through the center of which a hole has been drilled and a plumb bob suspended; lowering the plumb bob to the top bellows; and raising the Instron crosshead to the lower bellows.

To prevent the Instron pen recorder from picking up vibrations from the roughing pump, the pump does not rest on the dolly when the unit is in the Instron. It normally sits on a plate, with four adjustable legs, which rests on two pads on top of the dolly base. When the chamber is in the Instron,

the four legs are lowered, raising the pump a fraction of an inch, and the pads slid out from between the plate and the dolly base.

In order to be able to disconnect and reconnect the upper jaw and bellows assembly from the load cell to calibrate the load cell, and to move the whole unit into and out of the Instron with the chamber under vacuum, the upper bellows assembly has been modified to take three bolts which allow the upper jaw to be easily raised and lowered. Further, in order to calibrate the Instron load cell with the furnace in the Instron, a special pan for holding the calibration weights that engages the load cell directly has been fabricated.

During the first few months of operation of the facility several electrical power failures occurred after working hours and while the mechanical pump and diffusion pump were running. Although FRL® has an emergency generating system, it takes several seconds to come on the line. During this delay the pump shut off and had to be started manually. The mechanical pump switch has, therefore, been changed so that when a power failure occurs the diffusion pump shuts off and stays off. However, the mechanical pump starts again when the emergency power comes on, and again when the emergency power goes off and the outside power comes back on. This prevents back-streaming of both the diffusion pump oil and mechanical pump oil. Oil back-streaming raises the minimum pressure than can be achieved, and usually necessitates disassembling the piping system and washing it out with solvent.

Preliminary tensile tests were made on nylon fabric at slightly elevated temperatures. It was noted in these tests that the fabric melted at temperatures indicated by the thermocouples protruding into the center of the chamber considerably below the melting temperature of nylon. This raised the question of whether the thermocouples in the chamber were indicating the true temperature of the test specimen.

Initially, four thermocouples were mounted in the vacuum chamber: two located at the geometric center of the hot zone and two bonded to the back heater. The heater is cylindrical in shape and forms the wall of the test chamber hot zone. One of the thermocouples is bonded to the heater one inch above the chamber center and the other one inch below. To mount these thermocouples two small holes were drilled in the back heater, a pair of thermocouple leads pulled through each hole until the bead fitted tightly against the edge of the hole, and the lead wires insulated and bonded to the back of the heater so as to hold the thermocouple tightly in place. The adhesive used is good only to 1000°F. When testing at higher temperatures these heating elements are replaced by another set of elements without thermocouples.

A series of tests were made with no specimen in the chamber. The temperatures indicated by all four thermocouples were determined with a precision potentiometer. Tests were made both with and without the jaws in place. When the jaws were not in place, the holes in the heat shields for the jaw extension rods were covered with pieces of sheet stainless steel. Temperature measurements were made both in vacuum and in nitrogen. As the results given in Table 1 show, the wall temperature is considerably higher than the temperature indicated by the thermocouples at the center of the chamber. The differences occur both in vacuum and in nitrogen, regardless of whether or not the jaws are in place or removed. However, the magnitude of the differences decreases when the jaws are removed and when nitrogen is introduced. The differences remain about the same when the time given the chamber to come to equilibrium is increased from 15 to 30 minutes.

The thermocouples were checked to see that they were accurate and connected properly by placing them all in a hot-air oven. All four thermocouples showed excellent agreement over a several hundred degree temperature range.

TABLE I

VACUUM CHAMBER TEMPERATURES

Atmosphere and Pressure	Time at Temperature (minutes)	Jaws	Wall Temperature (°F) Top Thermocouple	Wall Temperature (°F) Bottom Thermocouple	Space Temperature (°F) Thermocouple #1	Space Temperature (°F) Thermocouple #2
Vacuum $1.0\text{-}10.0 \times 10^{-8}$ torr	--*	in	68	68	68	75
	15	in	100	107	64	75
	15	in	200	226	90	93
	15	in	300	321	128	127
	15	in	379	401	170	165
	15	in	480	506	236	224
	30	in	480	501	240	230
	15	out	94	106	65	79
	15	out	191	230	104	115
	--*	out	72	73	73	75
	30	out	300	328	157	159
Nitrogen 0.5 psig	15	in	100	91	79	83
	15	in	200	160	128	138
	15	in	300	237	177	186
	15	in	400	308	230	240
	15	in	500	381	283	296
	15	in	600	455	352	366
	15	in	700	526	413	429
	30	in	704	529	411	429
	15	out	100	88	78	91
	15	out	200	152	124	138
	15	out	300	220	170	182

*Chamber at room temperature, cooling water off.

It was initially believed that because of the geometric configuration of the vacuum chamber hot zone, it would behave like a black body. If the chamber did so behave, the temperature would be everywhere the same and the test specimen would be at the same temperature as the wall. However, it quickly became evident that this is not the case.

Since the vacuum chamber is equipped with a sighting port, the feasibility of determining the temperature of test specimens with an infrared pyrometer was investigated with the assistance of Barnes Engineering Company. These instruments do not indicate the target temperature directly; they measure the total radiation received. Therefore, when sighting into the vacuum furnace the instrument reads both the radiation emitted by the fabric target and the radiation emitted by the oven heaters and reflected from the fabric into the instrument. Thus, determination of the temperature of a fabric test specimen in a vacuum furnace with an infrared pyrometer requires solving the following expression.

$$W = K\epsilon_f T_f^4 + K(\rho_f)\,\epsilon_h T_h^4$$

W = pyrometer reading

K = the Boltzmann constant

ϵ_f = fabric emissivity

T_f = fabric test specimen temperature

$\rho_f = (1 - \epsilon_f)$ = fabric reflectivity. This assumes that no thermal radiation is transmitted through the test specimen.

ϵ_h = heater emissivity

T_h = heater temperature.

The emissivity of the heater can be determined by making measurements with no sample in place.

$$\epsilon_h = \frac{W_1}{K T_h^4}$$

where W_1 is the instrument reading with no test specimen.

As the above expressions show, the determination of the fabric test specimen temperature also requires knowing the fabric emissivity. The emissivities of metal and glass fabrics are probably approximately constant with increasing temperature in a vacuum. A suitable value could probably be determined in air at a temperature of about 150°F using the following procedure. Spray half of a piece of the fabric about 1 inch by 6 inches in size with 3M velvet black enamel* and allow it to dry. This paint has an emissivity very close to one. Place the fabric on a hot plate heated to about 150°F. Measure the radiation from both the painted and unpainted portion of fabric. Also measure the radiation from a piece of the unpainted fabric at ambient temperature and from a piece of black cardboard at ambient temperature. The fabric emissivity would then be given by the following expression:

$$\epsilon_f = \frac{W_1 - W_2}{W_3 - W_4}$$

where W_1 = radiation from heated, unpainted fabric

W_2 = radiation from unpainted fabric at ambient temperature

W_3 = radiation from heated, painted fabric

W_4 = radiation from black cardboard at ambient temperature.

Although this method may be suitable for determining the temperature of metal and glass fabric test specimens in a vacuum, it would not be suitable for use with polymeric fabrics because of the probable variation of their emissivity with increasing temperature. The emissivity of polymeric fabrics would also probably be different in a vacuum at elevated temperatures than in air.

Determination of the emissivity of polymeric fabrics at elevated temperatures in a vacuum does not appear to be a simple task. It would require heating the fabric in a vacuum, determining the fabric temperature by some means and comparing this reading to that given by an infrared pyrometer. In other words, it would require knowing the temperature of the fabric.

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*Manufactured by Minnesota Mining and Manufacturing Co., St. Paul, Minnesota.

After consideration of the above findings and discussions with other researchers in the field, it was decided that the best method for measuring the temperature of fabric test specimens being tensile tested in a vacuum furnace is to insert a thermocouple (10-mil Chromel-Alumel) in a pocket between the test specimen and the jaw lining, as shown in Figure 2.[2] The pocket is formed by loosely stitching an extension of the jaw lining, which is of the same material as the test specimen, to the test specimen, with the thermocouple located approximately at the center of the test specimen. Care is taken to prevent the stitching and jaw lining from restricting the test specimen extension. It is believed that this method gives the best measurement of the true test specimen temperature.

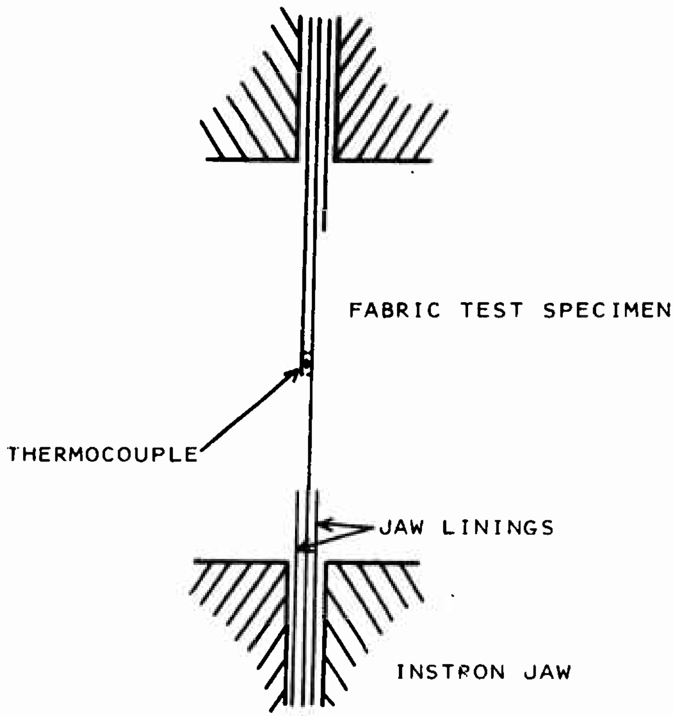

FIGURE 2. FABRIC TEMPERATURE MEASUREMENT

SECTION III

TENSILE PROPERTIES OF FABRICS IN VACUUM

The constructions of the fabrics tensile tested at ambient and elevated temperatures in vacuum are given in Table 2. The tensile properties of the fabrics at standard conditions and in vacuum are given in Tables 3 through 10. All the data is for tests performed in the warp direction only. One-inch wide ravelled-strip test specimens and a three-inch gauge length were used throughout. With one exception the fabrics were tested at a jaw speed of 3.0 inches per minute (strain rate of 100% per minute); the graphite was tested at 0.3 inch per minute. A minimum of five specimens were evaluated at each test condition.

For those fabrics that exhibited a yield, the yield elongation (expressed in %) and yield load (lbs/inch width of fabric) are given. These were taken from the load-elongation curve at the point where the bisector of the angle formed by the extrapolation of the pre- and post-yield portions of the load-elongation curve intersected the load-elongation curve. The modulus, rupture elongation (%) and rupture load (lbs/inch width) of the fabrics are also given in the Tables. The tensile moduli values given represent the slope of the initial linear portion of the fabric load-elongation curves in pounds per inch width of fabric per unit strain. All elongations and moduli reported are based on the at-temperature gauge length. This was accomplished by carefully mounting the test specimens with exactly three inches of free fabric length between jaws with the use of a sample-mounting jig. The jaws and test specimen were then inserted in the chamber with the distance between jaws being less than three inches during the dwell time. The at-temperature gauge length was then taken as the distance between jaws plus the jaw travel to where a load build-up was indicated. The thermal expansion of the jaw system was neglected. Since only a short length of the jaws extend into the hot-zone and the jaws are water cooled, the error in the moduli and elongation data resulting from neglecting the thermal expansion of the jaw system should be small.

TABLE 2

FABRICS TESTED

Material	Yarn Construction	Weave Pattern	Ends per Inch	Picks per Inch	Weight (oz/yd^2)
Nylon	100/34/6Z	MIL-C-7350-I	72	70	2.0
Dacron	46/34/25Z	2 x 1 twill	137	73	1.7
Nomex	100/50/4Z	MIL-C-7350-I	76	75	2.0
PBI	100/25/3Z warp 100/25/2Z filling	MIL-C-7350-I	75	74	2.1
Graphite	538 denier	8-shaft satin	52	49	7.6
S/181 Fiberglas greige; heat-cleaned	203/3-190-5Z/5S	8-shaft satin	58	58	8.7
Chromel R	10/10/1,3S/3Z 0.5-mil wire	2 x 2 basket	81	82	20.0

All of the polymeric fabric test specimens shrank during the dwell time at elevated temperatures. The magnitude of the shrinkage varied with the temperature and the material. Nylon exhibited negligible shrinkage below 300°F, an apparent shrinkage of 7% at 400°F and 9% at 450°F; Dacron, negligible shrinkage below 500°F and approximately 10% at 500°F; Nomex, negligible shrinkage below 700°F and approximately 3% at 700°F; PBI, negligible shrinkage below 800°F and approximately 30% at 800°F. However, as previously noted, although all test specimens were mounted with three inches of fabric between jaws, the jaw spacing was decreased to allow free sample contraction during the dwell time; the fabric specimens were not under a pre-load at the start of the test. (It is cautioned that these shrinkage values can only be considered as very approximate because of: (1) the specimen mounting procedure, (2) the unknown magnitude of the thermal expansion of the jaw system.)

TABLE 3

TENSILE PROPERTIES OF NYLON FABRIC IN VACUUM[1]

Pressure at Time of Test (torr x 10^{-5})	Time in Vacuum	Specimen Temp (°F)	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)	Space Temp (°F)
ambient	---	70 (65%RH)		Indefinite	661	25.3	106	70	70
					634	25.0	106		
					660	25.2	106		
					690	24.0	104		
					666	23.5	106		
Avg[2]					662	24.6	106		
0.78	1 hr	70		Indefinite	780	20.2	104	70	70
0.88					---	19.5	102		
0.87					776	20.2	103		
0.82					779	22.0	104		
0.41					835	21.4	106		
Avg[3] 0.75					793	20.7	104		
0.28	16 hrs	70		Indefinite	858	21.6	98	70	70
0.20					842	22.7	103		
0.11					855	22.5	103		
0.31					860	21.9	103		
0.21					882	21.9	107		
Avg[3] 0.22					859	22.1	103		

1. Fabric tested in warp direction using a gauge length of 3 inches and a jaw speed of 3.0 inches per minute.
2. Tests performed using flat, leather-lined jaws.
3. Tests performed using serrated jaws lined with two layers of nylon fabric.

TABLE 3 (Cont.)

TENSILE PROPERTIES OF NYLON FABRIC IN VACUUM

Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum	Specimen Temp (°F)	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)	Space Temp (°F)
2.4	64 hrs	70		Indefinite	881	22.9	102	70	70
3.5					935	22.0	103		
2.7					949	21.5	104		
2.8					975	21.2	103		
2.8					801	20.8	103		
Avg[1] 2.8					908	21.7	103		
0.073	13-2/3 days	70		Indefinite	886	22.4	103[1]	70	70
0.070	40 days				857	22.3	105[1]		
2.8	27 days				944	21.3	102[1]		
3.0	8 days				913	21.5	101[1]		
5.8	5 days				930	20.8	100[1]		
3.6	5 days				784	19.3	97[1]		
3.1	30 days				938	19.9	101[1]		
4.9	32 days				910	20.8	102[1]		

1. Tests performed using serrated jaws lined with two layers of nylon fabric.

TABLE 3 (Cont.)

TENSILE PROPERTIES OF NYLON FABRIC IN VACUUM

	Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum[2]	Specimen Temp (°F)[3]	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)[4]	Space Temp (°F)
	4.4	75 ±2 min	200	18.5	70.6	493	23.9	76.4	359	115
	4.0	(~ 4 min	(200^{+8}_{-4})	17.8	70.3	432	23.1	75.6	375	113
	3.7	heat-up		Indefinite		538	23.6	84.1	360	120
	3.9	time)		Indefinite		536	23.0	80.1	339	113
	3.1			19.3	76.4	522	24.2	82.3	340	106
Avg[1]	3.8					504	23.6	79.7	355	113
	3.3	75±2 min	300	18.0	54.8	404	32.0	61.8	482	177
	3.2	(~5 min	(300^{+5}_{-4})	19.0	54.7	420	34.4	64.0	483	169
	3.1	heat-up		19.1	53.7	405	34.8	62.4	486	172
	3.2	time)		19.4	53.6	392	37.4	63.6	484	170
	3.2			19.3	54.1	395	34.2	62.2	486	178
Avg[1]	3.2			19.0	54.2	403	34.6	62.8	484	173

1. Tests performed using serrated jaws lined with two layers of nylon fabric.
2. Includes 15 minutes dwell time at temperature.
3. Average temperature variation noted is during dwell time; the variation was ±2°F or less during the test.
4. Average of two thermocouples.

TABLE 3 (Cont.)

TENSILE PROPERTIES OF NYLON FABRIC IN VACUUM

	Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum[2]	Specimen Temp[3] (°F)	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp[4] (°F)	Space Temp (°F)
	3.0	75^{+4}_{-2} min	400	22.7	37.3	199	50.9	49.6	502	310
	2.7		(400^{+5}_{-3})	19.6	37.4	247	51.6	50.4	600	277
	2.9	(~5 min		24.5	38.6	223	51.7	48.2	611	266
	2.9	heat-up		23.9	38.3	217	54.8	48.2	572	305
	3.0	time)		21.8	37.8	225	51.8	53.8	520	261
Avg[1]	2.9			22.5	37.9	222	52.2	50.0	561	284
	3.2	75^{+3}_{-1} min	450	Indefinite		106	42.1	31.3	574	326
	3.2		(450^{+4}_{-3})			121	32.1	29.8	578	331
	3.1	(~4 min				103	28.4	24.7	583	333
	3.1	heat-up				129	42.9	32.3	554	338
	3.1	time)				126	50.0	36.5	562	354
Avg[1]	3.1					117	39.1	30.9	570	336
	3.4	75^{+0}_{-2} min	475	Indefinite		82	12.7	7.8	619	363
	3.4		(475^{+4}_{-5})			79	7.7	2.8	662	343
	3.5	(~4 min				87	13.1	9.4	653	319
	3.1	heat-up time)				79	6.1	2.7	581	332
Avg[1]	3.4					82	9.9	5.7	629	339

1. Tests performed using serrated jaws lined with two layers of nylon fabric.
2. Includes 15 minutes dwell time at temperature.
3. Average temperature variation noted is during dwell time; the variation was ±2°F or less during the test.
4. Average of two thermocouples.

TABLE 4

TENSILE PROPERTIES OF DACRON FABRIC IN VACUUM[1]

Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum	Specimen Temp (°F)	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)	Space Temp (°F)
ambient	---	70	2.4	12.1	692	22.4	54.8	70	70
		(65% RH)	2.4	12.1	704	22.4	54.0		
			2.3	12.1	684	23.3	55.3		
			2.1	12.0	730	23.5	55.3		
			2.2	12.7	764	21.4	56.5		
Avg[2]			2.3	12.2	715	22.6	55.2		
3.1	1 hr	70	2.1	11.8	784	23.6	57.8	70	70
2.9			2.2	11.9	757	23.1	50.6		
2.9			2.1	12.3	693	21.9	53.3		
3.7			2.1	12.0	769	20.1	48.3		
3.4			2.2	12.5	693	23.0	56.2		
Avg[3] 3.2			2.1	12.1	739	22.3	53.2		
2.5	16 hrs	70	2.3	13.0	769	23.1	58.9	70	70
2.7			2.3	13.0	771	24.0	58.2		
2.6			2.0	12.8	772	23.9	58.0		
2.7			2.1	12.5	741	21.9	53.8		
2.7			2.3	12.2	701	23.0	54.7		
Avg[3] 2.6			2.2	12.7	751	23.2	56.7		
2.7	64 hrs	70	2.1	12.5	714	23.5	55.0	70	70
3.0			2.1	11.8	720	21.2	54.0		
2.6			2.3	12.0	694	21.8	58.0		
3.0			2.0	12.3	776	22.7	57.4		
2.7			2.1	12.0	767	22.1	54.7		
Avg[3] 2.8			2.1	12.1	734	22.3	55.8		

1. Fabric tested in warp direction using a gauge length of 3 inches and a jaw speed of 3.0 inches per minute.
2. Tests performed using flat, tape-lined jaws.
3. Tests performed using serrated jaws lined with two layers of Dacron fabric.

TABLE 4 (Cont.)

TENSILE PROPERTIES OF DACRON FABRIC IN VACUUM

	Pressure at Time of Test (torr x 10^{-5})	Time in Vacuum[2]	Specimen Temp (°F)[3]	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)[4]	Space Temp (°F)
	3.4	75±3 min	200	1.9	6.8	484	22.5	44.0	230	125
	4.0	(~ 3 min	(200^{+2}_{-2})	2.0	6.7	454	22.1	43.0	232	132
	4.1	heat-up		1.9	7.0	522	21.9	42.8	229	124
	3.2	time)		2.0	7.4	447	20.7	41.2	213	118
	2.9			1.9	7.8	500	21.1	45.5	236	123
Avg[1]	3.5			1.9	7.1	481	21.7	43.3	228	124
	3.6	75^{+1}_{-2} min	300	Indefinite		276	23.6	36.2	321	208
	4.4	(~ 4 min	(300^{+4}_{-3})			256	25.7	34.7	342	192
	3.0	heat-up				264	20.2	33.3	328	205
	3.8	time)				263	24.1	34.2	307	198
	3.5					250	22.3	33.4	322	190
	5.8					260	21.8	34.6	335	189
Avg[1]	4.0					262	23.0	34.4	326	197
	3.6	75^{+0}_{-1} min	400	19.8	25.1	209	30.7	27.7	439	286
	4.1	(~4 min	(400^{+4}_{-1})	23.6	27.7	200	34.0	30.6	428	294
	3.7	heat-up		19.7	25.3	206	30.3	28.5	434	290
	4.2	time)		19.9	24.3	206	31.5	27.5	428	288
	3.8			24.5	25.8	174	33.5	28.3	436	293
Avg[1]	3.9			21.5	25.6	199	32.0	28.5	433	290
	3.4	75±1 min	475	None		125	20.3	9.1	516	362
	4.4	(~5 min	(475^{+3}_{-3})	None		92	27.4	11.3	542	375
	4.0	heat-up		Indefinite		123	29.9	17.8	546	371
	4.2	time)		None		104	27.4	15.1	568	372
	3.8			Indefinite		117	37.1	19.3	534	381
Avg[1]	4.0					112	28.4	14.5	541	372

1. Tests performed using serrated jaws lined with two layers of Dacron fabric.
2. Includes 15 minutes dwell time at temperature.
3. Average temperature variation noted is during dwell time; the variation was ±2°F or less during the test.
4. Average of two thermocouples.

TABLE 5

TENSILE PROPERTIES OF NOMEX FABRIC IN VACUUM[1]

Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum	Specimen Temp (°F)	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)	Space Temp (°F)
ambient	---	70 (65%RH)		Indefinite	1610	24.5	106	70	70
					1500	24.3	102		
					1590	25.3	105		
					1580	24.4	102		
					1570	24.7	106		
Avg[2]					1570	24.6	104		
6.2	1 hr	70		Indefinite	1510	20.0	109	70	70
5.7					1430	19.3	106		
5.3					1360	19.8	105		
5.1					1400	21.0	104		
5.3					1380	19.8	104		
Avg[3] 5.5					1420	20.0	106		
0.15	16 hrs	70		Indefinite	1600	19.9	107	70	70
0.12					1430	19.4	106		
0.25					1460	20.5	107		
2.5					1410	21.2	107		
2.8					1310	20.1	104		
2.7					1440	20.6	109		
Avg[3] 1.42					1440	20.3	107		
3.0	64 hrs	70		Indefinite	1670	20.3	123	70	70
3.0					1540	20.6	104		
2.9					1670	18.7	106		
2.5					1690	17.9	107		
3.0					1650	20.2	109		
Avg[3] 2.9					1640	19.6	110		

1. Fabric tested in warp direction using a gauge length of 3 inches and a jaw speed of 3.0 inches per minute.
2. Tests performed using flat, leather-lined jaws.
3. Tests performed using serrated jaws lined with three layers of Nomex fabric.

TABLE 5 (Cont.)

TENSILE PROPERTIES OF NOMEX FABRIC IN VACUUM

	Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum[2]	Specimen Temp (°F)[3]	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)[4]	Space Temp (°F)
	3.6	75±2 min	200	Indefinite		1360	17.8	93.5	305	108
	3.8	(~5 min	(200^{+7}_{-7})			1460	20.4	94.0	290	115
	3.6	heat-up				1340	18.1	94.0	306	117
	3.6	time)				1260	17.3	92.0	294	112
	3.6					1250	19.6	94.5	289	115
Avg[1]	3.6					1330	18.6	93.6	297	113
	3.9	75±7 min	300	Indefinite		1200	16.8	79.8	411	188
	3.8	(~8 min	(300^{+6}_{-6})			1230	19.3	81.0	409	172
	3.9	heat-up				1160	18.2	80.0	404	173
	3.7	time)				1140	17.3	77.3	379	173
	4.1					1160	18.7	78.2	420	185
Avg[1]	3.9					1180	18.1	79.3	405	178
	4.5	75^{+11}_{-2} min	400	Indefinite		1120	17.8	66.1	524	255
	4.2	(~9 min	(300^{+3}_{-3})			1070	19.5	67.9	514	304
	3.9	heat-up				1120	18.5	71.5	499	294
	4.2	time)				990	20.1	66.7	560	341
	3.8					1100	19.6	66.3	565	330
Avg[1]	4.1					1080	19.1	67.7	532	305

1. Tests performed using serrated jaws lined with three layers of Nomex fabric.
2. Includes 15 minutes dwell time at temperature.
3. Average temperature variation noted is during dwell time; the variation was ±2°F or less during the test.
4. Average of two thermocouples.

TABLE 5 (Cont.)

TENSILE PROPERTIES OF NOMEX FABRIC IN VACUUM

	Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum[2]	Specimen Temp (°F)[3]	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)[4]	Space Temp (°F)
	4.8	75^{+0}_{-3} min	500	Indefinite		894	18.9	52.8	682	429
	4.0	(~ 12 min	(500^{+3}_{-3})			940	18.7	54.3	656	407
	3.8	heat-up				865	19.5	55.0	644	408
	3.7	time)				874	19.2	51.8	675	410
	3.8					944	19.1	52.3	665	401
Avg[1]	4.0					903	19.1	53.2	664	411
	5.4	75^{+3}_{-0} min	600	Indefinite		375	19.4	40.2	738	514
	4.6		(600^{+3}_{-3})			366	19.4	39.5	750	512
	4.1	(~ 13 min				362	19.9	40.3	753	516
	4.0	heat-up				364	19.5	42.7	749	523
	3.9	time)				368	18.1	41.7	747	511
Avg[1]	4.4					367	19.3	40.9	747	515
	8.5	75^{+8}_{-5} min	700	None		228	12.4	22.6	825	598
	4.8					226	13.7	22.4	832	605
	4.3	(~ 24 min	(700^{+4}_{-4})			232	13.8	24.6	828	618
	4.4	heat-up				242	13.3	23.9	832	617
	5.3	time)				250	14.4	25.1	846	625
Avg[1]	5.5					236	13.5	23.7	833	613
	7.7	75^{+0}_{-6} min	750	None		131	15.3	14.2	836	624
	7.2					105	15.3	12.1	853	641
	5.5	(~ 30 min	(750^{+4}_{-4})			163	15.0	16.8	826	633
	6.2	heat-up				134	12.7	14.0	843	644
	7.2	time)				126	16.7	14.2	845	639
Avg[1]	6.8					132	15.0	14.3	841	636

1. Tests performed using serrated jaws lined with three layers of Nomex fabric.
2. Includes 15 minutes dwell time at temperature.
3. Average temperature variation noted is during dwell time; the variation was ± 2 °F or less during the test.
4. Average of two thermocouples.

TABLE 6

TENSILE PROPERTIES OF PBI FABRIC IN VACUUM[1]

Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum	Specimen Temp (°F)	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)	Space Temp (°F)
ambient	---	70	7.7	52	987	21.7	66	70	70
		(65% RH)	7.8	57	938	19.8	69		
			8.1	57	1030	19.3	69		
			7.9	56	1010	17.2	69		
			8.0	56	1040	18.8	69		
Avg[2]			7.9	56	1000	19.4	69		
1.2	1 hr	70	7.4	55	988	15.5	72	70	70
1.7			7.1	51	1030	16.5	68		
1.0			7.3	50	1030	18.0	70		
0.9			7.5	51	1000	17.1	71		
0.9			7.4	52	1030	16.1	71		
0.9			7.3	52	1010	17.2	68		
Avg[3] 1.1			7.3	52	1010	16.7	70		
0.21	16 hrs	70	6.9	48	879	16.9	67	70	70
0.16			6.8	47	899	17.2	68		
0.48			6.8	50	978	16.2	67		
0.52			7.0	48	1050	16.5	67		
0.29			7.2	50	996	16.2	66		
Avg[3] 0.33			6.9	49	960	16.6	67		
0.11	64 hrs	70	7.1	50	1040	16.4	64	70	70
0.17			7.6	49	980	18.2	64		
0.14			6.8	47	920	19.6	65		
2.8			7.3	49	990	19.8	67		
2.6			7.2	50	1010	18.6	68		
Avg[3] 1.2			7.2	49	990	18.5	66		

1. Fabric tested in warp direction using a gauge length of 3 inches and a jaw speed of 3.0 inches per minute.
2. Tests performed using flat, leather-lined jaws.
3. Tests performed using serrated jaws lined with two layers of PBI fabric.

TABLE 6 (Cont.)

TENSILE PROPERTIES OF PBI FABRIC IN VACUUM

Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum[2]	Specimen Temp (°F)[3]	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)[4]	Space Temp (°F)
5.0	75$\pm$1 min	200	6.8	44.3	934	19.8	66.9	346	122
4.8	(~ 14 min	(200^{+5}_{-5})	6.6	44.3	959	19.6	62.2	349	120
4.9	heat-up		6.9	42.3	888	20.9	61.7	344	131
4.6	time)		6.3	42.7	997	20.0	62.4	341	124
4.6			6.5	43.6	955	20.0	65.8	347	128
Avg[1] 4.8			6.6	43.4	947	20.1	63.8	345	125
6.8	75$\pm$3 min	400	6.9	43.7	923	20.6	57.4	579	287
6.6	(~ 24 min	(400^{+3}_{-3})	7.1	41.5	868	19.5	55.8	585	284
5.2	heat-up		7.0	43.0	935	20.6	57.7	568	285
7.6	time)		6.8	41.4	893	21.8	57.8	572	277
6.0			6.6	42.5	960	19.8	59.8	563	283
Avg[1] 6.4			6.9	42.4	916	20.5	57.7	573	283
3.7	75^{+3}_{-5} min	600	6.1	26.4	604	23.5	44.7	724	535
3.2	(~ 30 min	(600^{+3}_{-3})	6.3	26.6	601	22.5	45.8	726	533
3.7	heat-up		6.8	27.0	577	23.5	44.3	726	530
3.4	time)		6.7	26.6	542	23.1	47.3	725	524
3.2			6.5	26.0	575	23.2	46.7	725	520
Avg[1] 3.4			6.5	26.5	580	23.2	45.8	725	528
4.3	75$\pm$3 min	700	6.3	17.0	388	30.8	34.3	826	579
4.0	(~ 33 min	(700^{+3}_{-3})	5.9	16.5	400	28.7	36.9	822	583
4.4	heat-up		7.5	18.1	390	31.9	33.7	846	585
3.8	time)		5.8	17.7	406	27.9	33.5	853	592
4.0			5.8	16.9	403	29.5	32.2	835	587
Avg[1] 4.1			6.3	17.2	397	29.8	34.1	836	585

1. Tests performed using serrated jaws lined with two layers of PBI fabric.
2. Includes 15 minutes dwell time at temperature.
3. Average temperature variation noted is during dwell time; the variation was $\pm$2°F or less during the test.
4. Average of two thermocouples.

TABLE 6 (Cont.)

TENSILE PROPERTIES OF PBI FABRIC IN VACUUM

	Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum[2]	Specimen Temp (°F)[3]	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)	Space Temp (°F)
	5.8	75^{+67}_{-0} min	800	43.3	8.0	31.9	75.6	8.3	923	708
	4.9		(800±6)	56.9	9.9	49.1	101.0	10.7	924	703
	4.4	(~48 min		8.2	4.2	111.8	58.7	10.7	904	689
	4.9	heat-up		57.8	8.5	28.1	86.5	9.4	913	699
	4.4	time)		19.8	5.4	51.6	68.8	11.4	910	690
Avg[1]	4.9			37.2	7.2	54.5	78.1	10.1	915	698

1. Tests performed using serrated jaws lined with two layers of PBI fabric, a gauge length of 2 inches and a jaw speed of 2.0 inches per minute.
2. Includes 15 minutes dwell time at temperature.
3. Average temperature variation noted is during dwell time, ±3°F or less during the test

TABLE 7

TENSILE PROPERTIES OF HEAT-CLEANED FIBERGLAS® FABRIC IN VACUUM[1]

Pressure at Time of Test (torr x 10^{+6})	Time in Vacuum	Specimen Temp (°F)	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch x 10^{-3})	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)	Space Temp (°F)
ambient	---	70 (65%RH)	None		10.3	3.4	260	70	70
					10.0	3.3	267		
					10.4	4.0	267		
					9.7	3.2	243		
					9.7	3.3	256		
					9.9	3.3	243		
					10.1	3.4	258		
Avg[2]					10.0	3.4	256		
3.0	1 hr	70	None		13.4	4.1	361	70	70
3.0					12.8	3.7	325		
2.9					13.7	3.7	362		
2.9					12.4	4.0	325		
3.1					14.7	3.7	370		
3.0					14.0	3.5	322		
3.5					13.2	3.6	329		
Avg[3] 3.1					13.5	3.8	342		
2.7	16 hrs	70	None		11.1	4.5	383	70	70
2.7					13.1	4.3	416		
2.9					13.0	4.1	349		
3.2					13.7	4.2	368		
3.0					11.9	4.5	417		
3.1					14.4	3.7	336		
3.4					14.3	3.7	322		
Avg[3] 3.0					13.1	4.3	370		

1. Fabric tested in warp direction using a gauge length of 3 inches and a jaw speed of 3.0 inches per minute.
2. Tests performed using flat, tape-lined jaws.
3. Tests performed using serrated jaws lined with two layers of Fiberglas® fabric.

TABLE 7 (Cont.)

TENSILE PROPERTIES OF HEAT-CLEANED FIBERGLAS® FABRIC IN VACUUM

	Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum	Specimen Temp (°F)	Yield Elong (°F)	Yield Load (lbs/inch)	Modulus (lbs/inch x 10^{-3})	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)	Space Temp (°F)
	3.7	64 hrs	70	None		14.0	3.5	358	70	70
	3.9					13.8	3.9	377		
	2.8					12.4	3.9	339		
	2.8					12.0	3.8	324		
	2.8					12.0	4.4	372		
Avg[1]	3.2					12.8	3.9	354		

1. Tests performed using serrated jaws lined with two layers of Fiberglas® fabric.

TABLE 7 (Cont.)

TENSILE PROPERTIES OF HEAT-CLEANED FIBERGLAS® FABRIC IN VACUUM

Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum[2]	Specimen Temp (°F)[3]	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch x 10^{-3})	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)[4]	Space Temp (°F)
3.0	75^{+0}_{-2} min	200		None	12.5	4.6	323	351	136
3.0		(200^{+6}_{-4})			12.8	3.7	369	383	135
3.0	(~ 4 min				14.6	3.7	358	294	127
3.2	heat-up				13.6	3.7	347	326	121
3.2	time)				13.5	4.0	406	323	152
3.0					14.2	3.6	394	328	155
2.8					13.4	3.5	367	336	154
Avg[1] 3.0					13.5	3.8	366	334	140
2.8	75^{+3}_{-1} min	400		None	12.6	4.1	353	566	338
3.0		(400^{+4}_{-3})			12.6	3.7	354	532	327
3.0	(~ 4 min				12.9	3.7	375	540	333
3.1	heat-up				12.9	3.5	337	526	330
3.1	time)				13.6	3.7	370	539	329
Avg[1] 3.0					12.7	3.7	358	541	331
5.6	75^{+21}_{-3} min	800		None	9.0	3.2	188	832	739
5.3		(800^{+6}_{-4})			10.6	2.6	205	846	730
4.1	(13 min				10.4	2.5	153	838	731
4.5	heat-up				11.4	2.3	148	852	730
4.6	time)				11.3	2.6	185	842	728
4.3					11.4	2.2	148	866	725
Avg[1] 4.7					10.6	2.6	170	846	731

1. Tests performed using serrated jaws lined with two layers of Fiberglas® fabric.
2. Includes 15 minutes dwell time at temperature.
3. Average temperature variation noted is during dwell time; the variation was ±2°F or less during the test.
4. Average of two thermocouples.

TABLE 7 (Cont.)

TENSILE PROPERTIES OF HEAT-CLEANED FIBERGLAS® FABRIC IN VACUUM

	Pressure at Time of Test (torr x 10^{+8})	Time in Vacuum[2]	Specimen Temp (°F)[3]	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch x 10^{-3})	Rupture Elong (%)	Rupture Load (lbs/inch width	Wall Temp (°F)[4]	Space Temp (°F)
	6.0	75^{+2}_{-4} min	1000		None	11.0	1.7	100	1066	968
	5.7		(1000^{+7}_{-5})			5.6	1.9	75	1064	957
	8.9	(~ 6 min				6.6	2.0	72	1070	965
	7.5	heat-up				6.9	1.8	63	1054	953
	5.7	time)				7.5	1.6	59	1020	950
Avg[1]	6.8					7.5	1.8	74	1055	959
	5.6	75^{+12}_{-5} min	1200		None	5.7	1.6	43	1196	1173
	6.2		(1200^{+6}_{-3})			4.2	1.7	28	1214	1166
	7.2	(~ [illegible] min				4.4	1.6	32	1210	1174
	7.3	heat-up				5.2	1.8	44	1207	1172
	7.4	time)				4.8	1.6	39	1202	1173
Avg[1]	6.7					4.9	1.7	37	1206	1172

1. Tests performed using serrated jaws lined with two layers of Fiberglas® fabric.
2. Includes 15 minutes dwell time at temperature.
3. Average temperature variation noted is during dwell time; the variation was ±2°F or less during the test.
4. Average of two thermocouples.

TABLE 8

TENSILE PROPERTIES OF GREIGE FIBERGLAS® FABRIC IN VACUUM[1]

Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum	Specimen Temp (°F)	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch x 10^{-3})	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)	Space Temp (°F)
ambient	---	70 (65%RH)		None	14.2	3.7	371	70	70
					15.8	3.8	370		
					12.9	4.1	332		
					11.3	4.5	328		
					12.6	4.5	380		
					12.6	4.3	377		
					12.8	4.1	374		
Avg[2]					13.2	4.1	362		
3.2	1 hr	70		None	14.3	4.5	500	70	70
2.9					14.6	4.5	541		
3.7					14.1	4.6	464		
3.2					14.1	4.7	538		
5.3					14.4	4.4	481		
Avg[3] 3.3					14.3	4.5	505		
3.6	16 hrs	70		None	14.1	4.5	533	70	70
4.1					13.9	4.9	580		
3.9					13.4	4.9	524		
4.1					13.4	5.0	505		
4.5					12.8	5.2	552		
Avg[3] 4.0					13.5	4.9	539		

1. Fabric tested in warp direction using a gauge length of 3 inches and a jaw speed of 3.0 inches per minute.
2. Tests performed using flat, leather-lined jaws.
3. Tests performed using serrated jaws lined with two layers of greige Fiberglas® fabric.

TABLE 9

TENSILE PROPERTIES OF GRAPHITE FABRIC IN VACUUM[1]

Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum	Specimen Temp (°F)	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch x 10^{-3})	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)	Space Temp (°F)
ambient	---	70 (65%RH)		Indefinite	10.0	1.6	101	70	70
					10.3	1.8	126		
					10.0	1.9	134		
					10.7	1.7	104		
					10.3	1.9	114		
Avg[2]					10.3	1.8	116		
3.0	1 hr	70		Indefinite	10.2	1.8	147	70	70
4.4					9.7	1.4	90		
3.6					9.8	1.5	94		
Avg[3] 3.7					9.9	1.6	110		
2.6	16 hrs	70		Indefinite	9.4	2.1	116	70	70
2.8					10.3	2.1	123		
3.3					10.8	1.7	133		
2.8					11.6	1.3	107		
3.2					9.9	1.4	82		
Avg[3] 2.9					10.4	1.7	112		

1. Fabric tested in the warp direction using a gauge length of 3 inches and a jaw speed of 0.3 inch per minute.
2. Tests performed using flat, leather-lined jaws.
3. Tests performed using serrated jaws lined with three layers of quartz fabric.

TABLE 10

TENSILE PROPERTIES OF CHROMEL R METAL FABRIC IN VACUUM[1]

Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum[4]	Specimen Temp (°F)[5]	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch x 10^{-3})	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)	Space Temp (°F)
ambient	---	70 (65%RH)	4.6	220	14.0	9.8	252	70	70
			4.4	221	14.3	9.0	247		
			4.4	218	13.6	8.2	239		
			4.3	217	13.0	8.8	244		
			4.6	219	11.5	7.9	235		
Avg[2]			4.5	219	13.3	8.7	243		
4.6	75^{+25}_{-0} min	1250	6.1	181	5.21	8.8	189	1294	1195
4.0		(1250^{+5}_{-5})	5.4	178	5.84	8.2	189	1295	1203
4.8	(~30 min		5.8	176	5.37	7.8	187	1294	1199
6.5	heat-up		5.7	182	5.67	10.4	190	1291	1203
6.4	time)		5.8	179	5.35	11.4	188	1233	1199
Avg[3] 5.3			5.8	179	5.49	9.3	189	1281	1200
5.0	75^{+50}_{-3} min	1500	Indefinite		2.45	21.3	78	1541	1500
7.2		(1500^{+23}_{-0})			2.44	23.9	75	1537	
7.4	(~ 40 min				2.14	24.7	71	1567	
5.9	heat-up				2.05	26.1	72	1553	
5.4	time)				2.10	26.7	74	1556	
Avg[3] 6.2					2.24	24.5	74	1551	

1. Fabric tested in the warp direction using a gauge length of 3 inches and a jaw speed of 3.0 inches per minute.
2. Tests performed using flat, leather-lined jaws.
3. Tests performed using serrated jaws lined with two layers of heat-cleaned quartz fabric.
4. Includes 15 minutes dwell time at temperature.
5. Measured with a thermocouple mounted as shown in Figure 2; average temperature variation noted is during dwell time; the variation was ± 2°F or less during the test.

TABLE 10 (Cont.)

TENSILE PROPERTIES OF CHROMEL R METAL FABRIC IN VACUUM

	Pressure at Time of Test (torr x 10^{+5})	Time in Vacuum (min)[2]	Specimen Temp (°F)[3]	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch x 10^{-3})	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)	Space Temp (°F)
	5.2	75^{+8}_{-12} min	1530	Indefinite		1.69	30.9	59	--[4]	1500
	5.3		----			2.03	29.3	63		
	3.3		1505			2.06	28.8	61		
	3.9		1520			1.91	28.9	62		
	3.7		1510			1.68	31.0	62		
Avg[1]	4.3		1516			1.87	29.8	61		
	3.2	75^{+7}_{-0} min	1730	Indefinite		0.916	20.0	31	--[4]	1750
	1.8		1720			0.919	20.2	31		
	1.9		1725			0.933	18.7	32		
	1.4		1720			0.786	20.2	31		
	1.9		1710			0.894	20.9	32		
Avg[1]	2.0		1721			0.890	20.0	31		
	1.9	100^{+21}_{-11} min	1940	Indefinite		0.794	15.6	17	--[4]	2000
	4.6		1960			0.670	16.1	17		
	2.5		1950			0.488	17.4	17		
	2.6		1940			0.455	16.7	17		
	2.0		1940			0.489	18.0	18		
Avg[1]	2.7		1946			0.579	16.8	17		

1. Tests performed with serrated jaws lined with two layers of heat-cleaned quartz fabric.
2. Includes 15 minutes dwell time at temperature.
3. Measured with an optical pyrometer.
4. Not measured.

The rupture elongations given in Tables 3-10 were taken at the point on the load-elongation curve where the first sudden, large drop in load occurred. For all materials, except the Chromel R metal fabric at 1500 to 2000°F, this either coincided with the point of maximum load or occurred immediately after the point of maximum load. The Chromel R fabric exhibits considerable elongation beyond the point of maximum load at temperatures above 1250°F (see Figure 26). All the elongations given in Table 10 for Chromel R fabric are to rupture.

During preliminary tests at 1500°F and a jaw speed of 0.3 inch/minute, the extension of the Chromel R fabric was found to be so large that the jaw contacted the extension stops before the sample broke. Therefore, all the results given in Table 10 are for a jaw speed of 3.0 inches/minute, as noted.

The fabrics were tensile tested initially at standard conditions with standard Instron flat jaws and with the vacuum chamber jaws to check that both procedures give the same results. The data given in the Tables for 70°F, 65% RH, ambient conditions was obtained using the standard Instron flat jaws.

The vacuum chamber jaws are serrated and in all cases were lined with two or three layers of the same fabric as the one being tested. The actual number of layers used in evaluating each material is noted in the Tables. It was arrived at by trial and is the number required to prevent both jaw breaks and slippage in the jaws. Additionally, the jaws were tightened with a torque wrench in an effort to further uniformize the testing.

The fabric test specimens were held at the test temperature for 15 minutes prior to testing. However, it usually took a considerable length of time to achieve the test temperature; the approximate time for each material and each temperature level is noted in the Tables. The approximate total time each test specimen was in the vacuum chamber is also noted in the Tables. This time includes the 15-minute dwell time and the heat-up time; it is the time interval between the pressure reaching about 1×10^{-3} torr and the Instron crosshead starting down. The long heat-up time used with some of the materials was necessary in order not to exceed a pressure of 10×10^{-5} torr as a consequence of the specimen outgassing. (For maximum heating element life the manufacturer recommends that the elements be operated only at pressures below 10×10^{-5} torr.)

The approximate range in temperature of the test specimens during the dwell time is noted in the tables for each temperature level. The temperature range during the actual tensile test was $\pm 3°F$ of the average, or less.

The temperature variation along the length of the fabric test specimens was investigated. One of the pieces of jaw lining was extended from the top jaw to the bottom jaw. Three thermocouples were inserted between the lining and the test specimen, one 1/4 inch below the top jaw, one at the center of the 3-inch spacing between jaws, and the third 1/4 inch above the bottom jaw. The variation in temperature along the test specimen length using a nylon fabric, was found to be $\pm 3\%$ of the average of the three readings at 400°F; using a Chromel R metal fabric, ± 1-1/2% at 1000°F and $\pm 1/2\%$ at 2000°F.

The temperature of the 2-1/2 inch diameter heaters which surround the test specimens is also noted in Tables 3-10. This was measured with thermocouples located in the vicinity of the test specimen and bonded to the inside face of the heater (see Section II). The temperature indicated by a thermocouple located at the center of the chamber is also given in the Tables.

The power to the heaters was decreased as the lower jaw moved downward during the test in order to maintain the desired temperature.

The pressure at the time of test is noted in the Tables. It varied from about 0.1×10^{-5} to 7×10^{-5} torr, depending on the material, temperature and length of exposure.

Glass fabric is normally supplied with a starch-oil finish. This finish reduces degradation caused by surface-to-surface contact of adjacent fibers and thereby improves the fabric strength. However, heat-cleaned glass fabric was used in the elevated temperature vacuum tests in order to avoid possible problems with outgassing of the starch-oil finish. Both heat-cleaned Fiberglas fabric and fabric of identical construction, but with the starch-oil finish not removed, i.e., a greige Fiberglas fabric, were evaluated in vacuum at 70°F. As a comparison of the data in Table 8 for the greige fabric to that in Table 7 for the heat-cleaned fabric shows, the greige fabric exhibits approximately a

41-1/2% larger rupture load at standard conditions and 47-1/2% larger rupture load at 70°F in vacuum after a one-hour exposure.

Test specimen clamping difficulties were encountered in testing both glass and graphite fabrics. The vacuum data given in Tables 7, 8, and 9 for these fabrics were obtained using serrated jaws lined with two layers of Fiberglas fabric. With this procedure, the Fiberglas test specimens broke in the gauge length at 1000 and 1200°F and exhibited a "broken-all-over" appearance at lower temperatures.

Late in the program efforts were made to develop an improved mounting procedure for testing Fiberglas and graphite fabric. The ends of the test specimens were impregnated with various ceramic and plastic materials and clamped in the jaws with several hundredths of an inch of the impregnated tail extending beyond the edge of the jaws to minimize the chance of failure at and in the jaws. Of the impregnating materials investigated, higher strengths were obtained for the Fiberglas fabric at standard conditions only with epoxy resin. The other materials were either too acidic or alkaline and degraded the glass fibers.

Preliminary results indicate that higher Fiberglas fabric strengths can also be obtained to about 800°F in air by impregnating the test specimen ends with epoxy resin. However, it is doubtful that this mounting procedure would be suitable for elevated temperature testing in vacuum because of excessive outgassing of the epoxy resin.

The graphite fabric evaluated had been graphitized in fabric form. No definitive conclusions can be drawn from the results obtained because of the considerable scatter in data (see Table 9). This was due to variation in the properties of the fabric from one location to another in the cloth roll, and also to the test specimen clamping difficulties mentioned previously. Consequently, no tensile testing was performed at elevated temperatures.

As noted in Tables 3 through 10, the polymeric fabrics and the heat-cleaned Fiberglas fabric were tensile tested in vacuum at 70°F after being in vacuum (at 70°F) for 1, 16, and 64 hours. (A few tests were also made on the nylon fabric after vacuum exposures of 5 to 40 days: see Table 3.) The greige Fiberglas

fabric and the graphite fabric were evaluated after 1- and 16-hour exposures. Since vacuum was not expected to have any effect on the tensile properties of 1/2-mil diameter wire, the Chromel R fabric was not evaluated at 70°F in vacuum.

The percent changes in the tensile properties of the fabrics with increasing lengths of time in vacuum, compared to their properties in 14.7 psi, 70°F, 65%RH air, are given in Table 11. As shown, vacuum has only a small effect, from +5.8% to -4.3%, on the rupture load of the polymeric fabrics. However, vacuum has a more significant effect on the rupture elongation of the fabrics; in general, the rupture elongation decreases and for nylon the modulus increases. The Dacron fabric exhibits only a small change in rupture elongation – from -1.3% to +2.7%; however, the other fabrics exhibit as much as a 20% decrease in elongation. The small effect of vacuum on the tensile properties of the Dacron fabric is probably due to the low moisture regain of the material.

With the exception of the modulus of the nylon fabric, increasing the length of the vacuum exposure from 1 to 64 hours appears to have little effect on the tensile properties of the fabrics.

As also shown in Table 11, both heat-cleaned and greige Fiberglas fabric exhibit a large increase – as much as 45% – in tensile strength in vacuum. The rupture elongation and modulus of the glass fabrics are also larger in vacuum. These property changes are evidently due to the removal of moisture from the surface of the glass fibers, thereby reducing stress-crack corrosion.

Both the heat-cleaned and greige Fiberglas fabrics were tensile tested in 14.7 psi, 70°F, 65%RH air after a 16-hour exposure in vacuum (70°F) and subsequently one hour in 70°F, 65%RH air. As a comparison of the results of these tests (see Table 12) to the data in Tables 7 and 8 shows, the fabrics exhibit approximately the same tensile properties after vacuum exposure and reconditioning as before; the improvement of Fiberglas fabric properties obtained in vacuum is not permanent.

TABLE 11

PERCENT CHANGE IN FABRIC PROPERTIES IN VACUUM

Material	Time in Vacuum (hrs)	Change in Modulus (%)	Change in Rupture Elongation (%)	Change in Rupture Load (%)
Nylon	1	+19.8	-15.9	-1.9
	16	+29.8	-10.2	-2.8
	64	+37.2	-11.8	-2.8
Dacron	1	+3 4	-1.3	-3.6
	16	+5.0	+2.7	+2.7
	64	+2.7	-1.3	+1.1
Nomex	1	-9.6	-18.7	+1.9
	16	-8.3	-17.5	+2.9
	64	+4.5	-20.3	+5.8
PBI	1	+1.0	-13.9	+1.4
	16	-4.0	-14.4	-2.9
	64	-1.0	-4.6	-4.3
Fiberglas (heat-cleaned)	1	+35.0	+11.8	+33.6
	16	+31.0	+26.5	+44.5
	64	+28.0	+14.7	+38.3
Fiberglas (greige)	1	+8.3	+9.8	+39.5
	16	+2.3	+19.5	+48.9

TABLE 12

TENSILE PROPERTIES OF FIBERGLAS® FABRIC AFTER VACUUM EXPOSURE[1]

Fabric	Time in Vacuum[2]	Specimen Temp (°F)	Yield Elong (%)	Yield Load (lbs/inch)	Modulus (lbs/inch x 10^{-3})	Rupture Elong (%)	Rupture Load (lbs/inch width)	Wall Temp (°F)	Space Temp (°F)
S/181 Heat-Cleaned	16 hrs	70 (65% RH)		None	8.4	4.0	269	70	70
					8.7	3.7	257		
					9.0	3.3	250		
					9.2	3.6	262		
					9.0	3.3	253		
Avg[3]					8.9	3.6	258		
S/181 Greige	16 hrs	70 (65% RH)		None	13.7	4.4	383	70	70
					13.6	4.5	388		
					12.7	4.2	371		
					13.2	4.8	412		
					12.0	4.4	341		
					13.8	4.2	383		
Avg[4]					13.2	4.4	380		

1. Fabric tested in warp direction using a gauge length of 3 inches and a jaw speed of 3.0 inches per minute.
2. Specimens conditioned 16 hours in a vacuum ([illegible].7 x 10^{-5} torr) and tested after 1 hour of conditioning in 14.7 psi, 70°F, 65% RH air.
3. Tests performed using flat, tape-lined jaws.
4. Tests performed using flat, leather-lined jaws.

As shown in Table 3, the nylon fabric was tensile tested at 70, 200, 300, 400, 450, and 475°F in vacuum. The fabric strength at 450°F is about 40% and at 475°F, 5% of its strength at standard conditions. The modulus at 450°F is about 17-1/2% of that exhibited at standard conditions and the rupture elongation three times greater.

The Dacron fabric was tested at 70, 200, 300, 400, and 475°F (see Table 4). It exhibits a strength at 475°F which is about 25%, a modulus which is about 64% and a rupture elongation which is about 131% of the values measured at standard conditions.

The Nomex fabric (see Table 5) was tested at 70, 200, 300, 400, 500, 600, 700, and 750°F. The strength at 750°F is approximately 13-1/2%, the modulus, 9.3% and the rupture elongation, 61% of the fabric properties at standard conditions.

Data for the PBI fabric are given in Table 6 for test temperatures of 70, 200, 400, 600, 700, and 800°F. The fabric strength at 700°F is approximately 50% of its strength at standard conditions; the rupture elongation, about 150%; and the modulus, 40%. Attempts to test the fabric at 800°F with a three-inch gauge length were unsuccessful. The material elongation was so great that the lower jaw contacted the extension stops before the sample broke. The fabric was retested using a 2-inch gauge length. The jaw speed was correspondingly reduced to 2.0 inches per minute in order to maintain the nominal 100% per minute strain rate. The fabric strength measured at 800°F is 14-1/2%, the modulus, 5-1/2% and the rupture elongation approximately 400% of the fabric properties at standard conditions.

The heat-cleaned Fiberglas fabric was tested at 70, 200, 400, 800, 1000, and 1200°F in vacuum (see Table 7). The fabric strength at 1200°F is approximately 15% of its tensile strength at standard conditions and 10% of its strength at 70°F in vacuum.

Data on the Chromel R multifilament-yarn, fine-wire fabric are given in Table 10. The fabric was tested at ambient temperatures and at 1250, 1500, 1750, and 2000°F in vacuum. In the 1250°F tests the specimen temperature was determined with a thermocouple using the technique shown in Figure 2. Two series of tests were made at 1500°F. For one, the temperature of the specimens was determined with a thermocouple and for the other, with an optical pyrometer.* The specimen temperatures given by both of these procedures agreed closely with the space temperature, i. e., the temperature indicated by a thermocouple extending into the center of the chamber. Consequently, the reason for the differences in the two sets of data is not readily apparent. The temperature of the test specimens in the 1750 and 2000°F tests was determined with the optical pyrometer.

The tensile strength of the Chromel R fabric in vacuum at 1500°F is 25-30%; at 1750°F, approximately 13%; and at 2000°F, 7% of the fabric strength at standard conditions. The fabric rupture elongation at 2000°F in vacuum is 193% of the elongation at standard conditions.

The tensile rupture load, rupture elongation and modulus of the nylon fabric in vacuum are plotted in Figures 3, 4, and 5, respectively, as a function of test temperature, and, similarly, for the Dacron fabric in Figures 6, 7, and 8; the Nomex fabric in Figures 9, 10, and 11; the PBI fabric in Figures 12, 13, and 14; the heat-cleaned Fiberglas fabric in Figures 15, 16, and 17, and for the Chromel R metal fabric in Figures 18, 19, and 20. Typical load-elongation diagrams of these fabrics at ambient and elevated temperatures in vacuum are given in Figures 21 through 26.

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*#8631-F, Leeds & Northrup Co., Philadelphia, Pa.

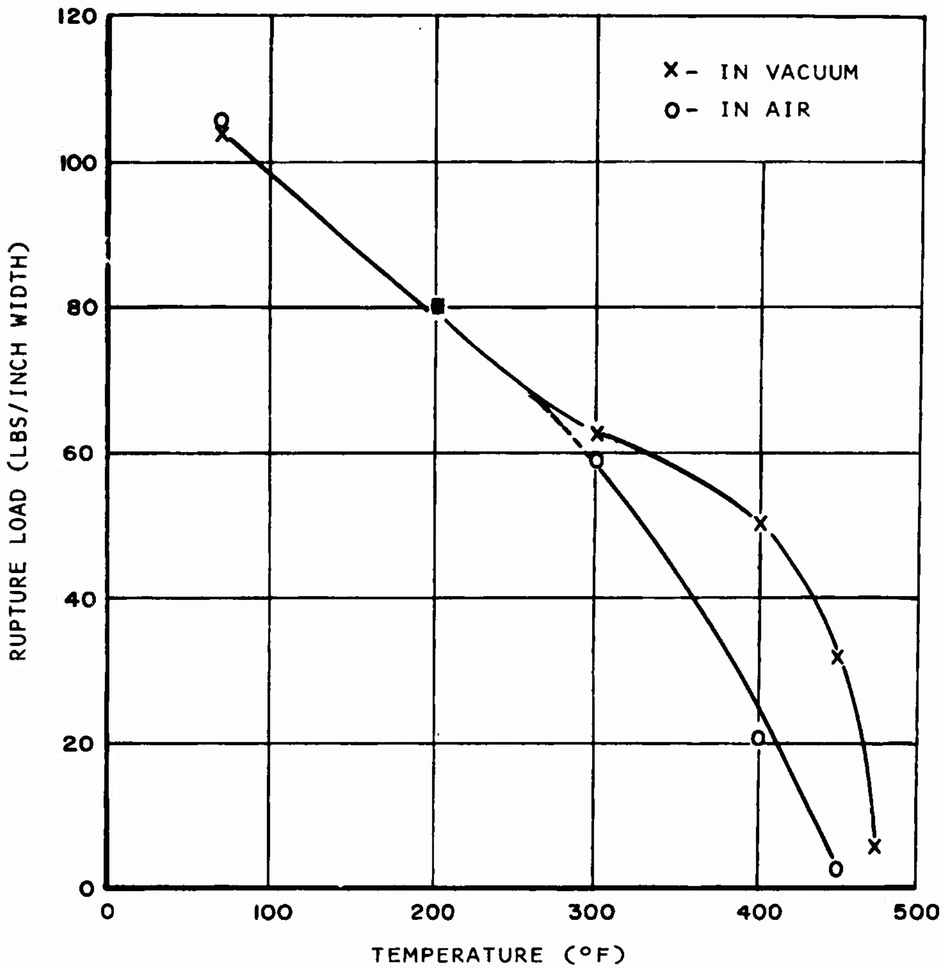

FIGURE 3. NYLON FABRIC RUPTURE LOAD AS A FUNCTION OF TEMPERATURE.

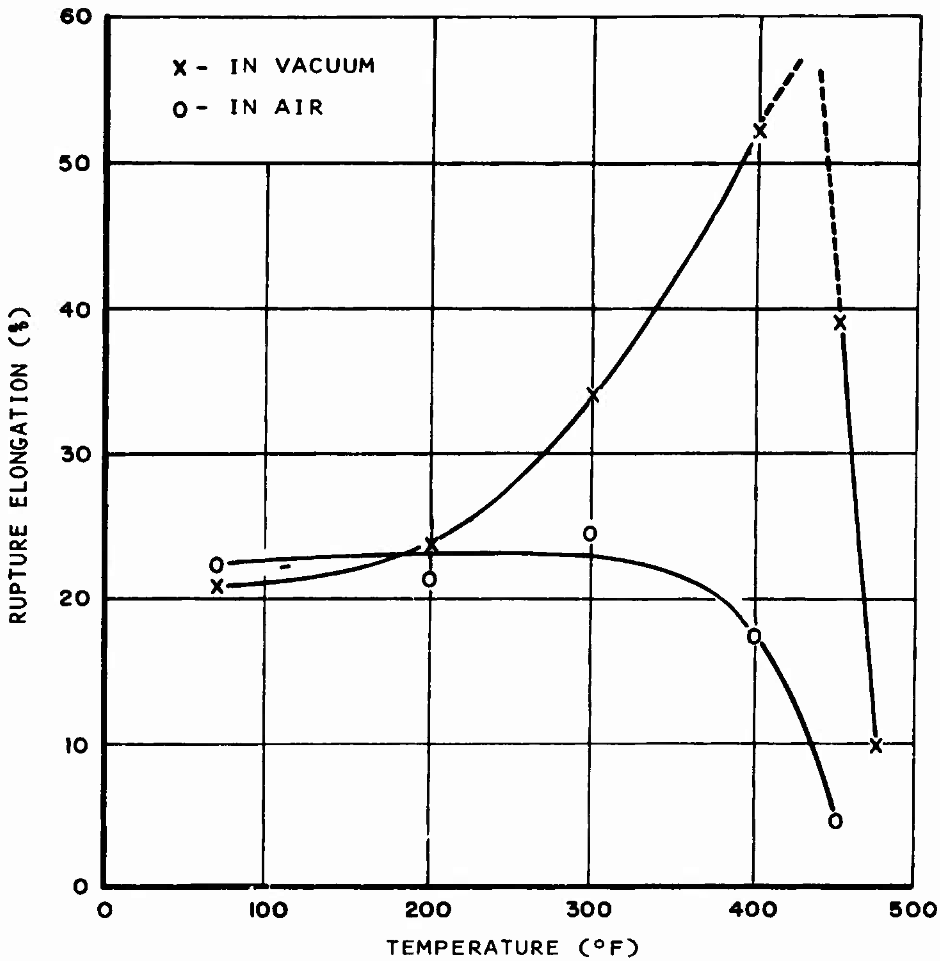

FIGURE 4. NYLON FABRIC RUPTURE ELONGATION AS A FUNCTION OF TEMPERATURE

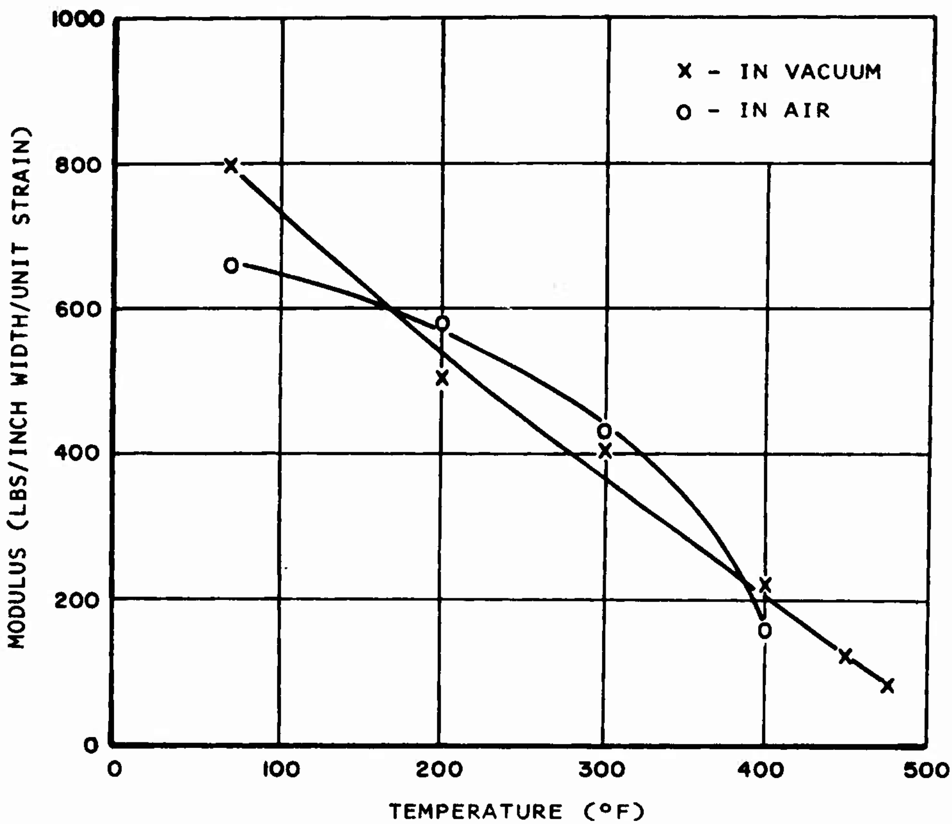

FIGURE 5. NYLON FABRIC TENSILE MODULUS AS A FUNCTION OF TEMPERATURE.

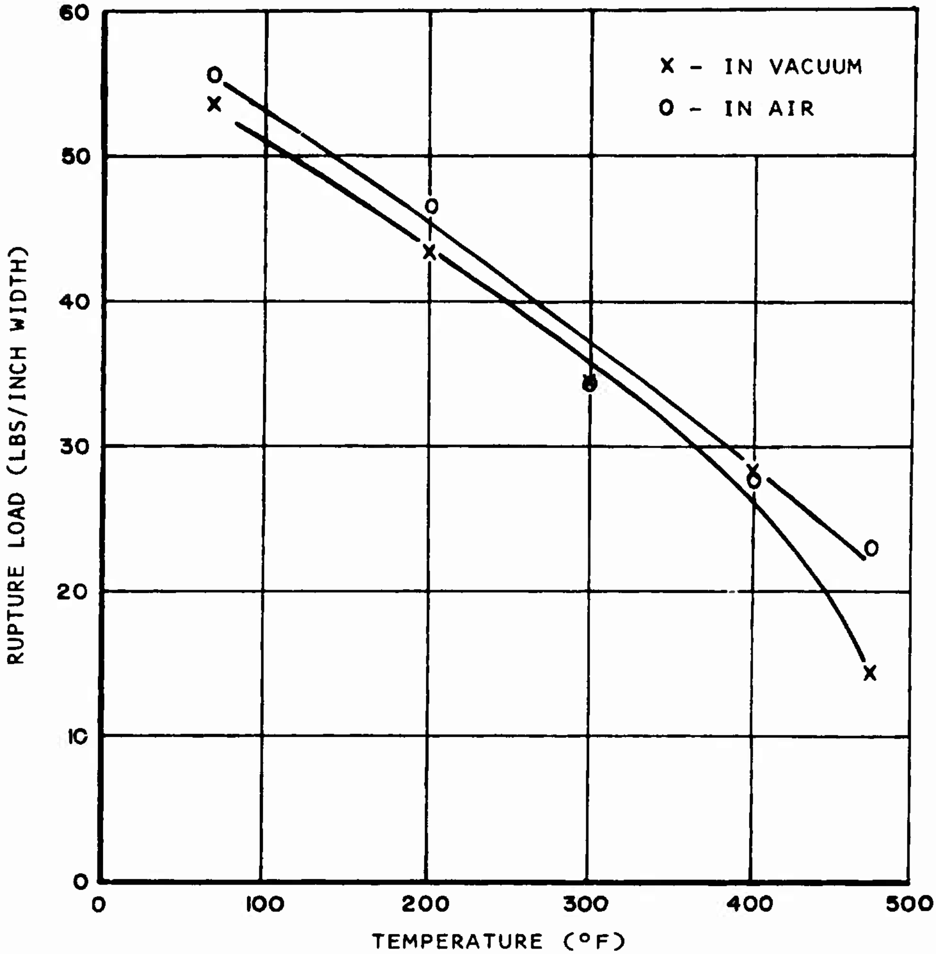

FIGURE 6. DACRON FABRIC RUPTURE LOAD AS A FUNCTION OF TEMPERATURE.

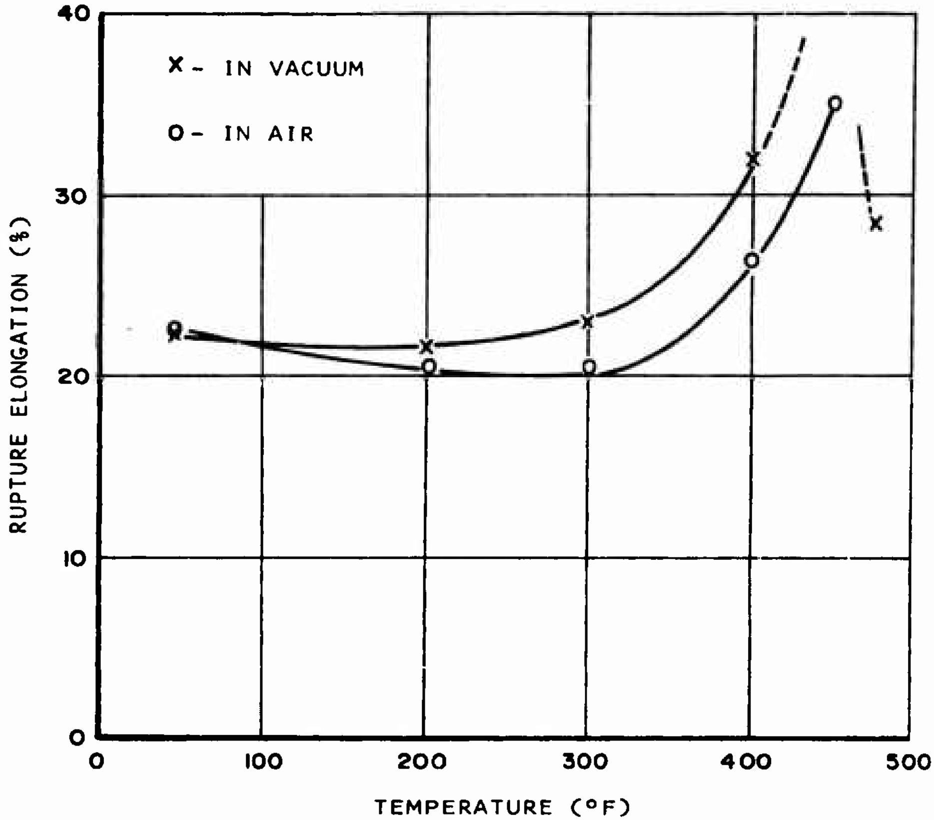

FIGURE 7. DACRON FABRIC RUPTURE ELONGATION AS A FUNCTION OF TEMPERATURE.

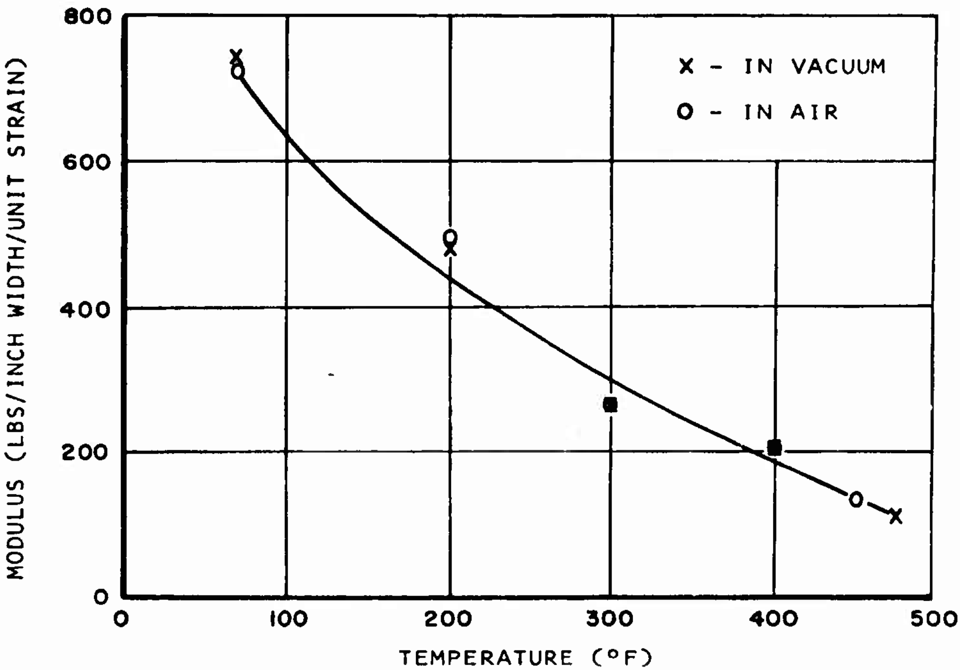

FIGURE 8. DACRON FABRIC TENSILE MODULUS AS A FUNCTION OF TEMPERATURE.

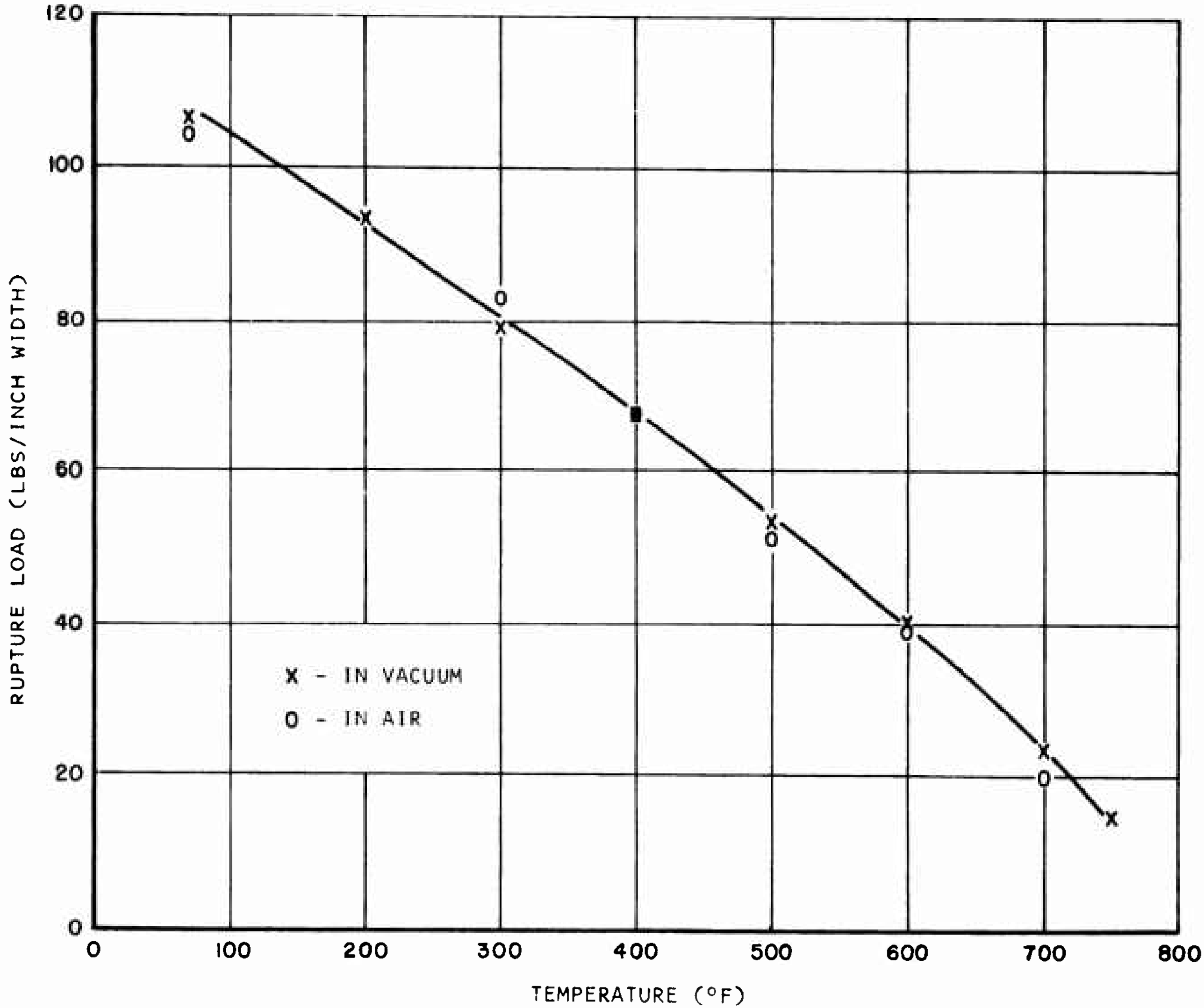

FIGURE 9. NOMEX FABRIC RUPTURE LOAD AS A FUNCTION OF TEMPERATURE.

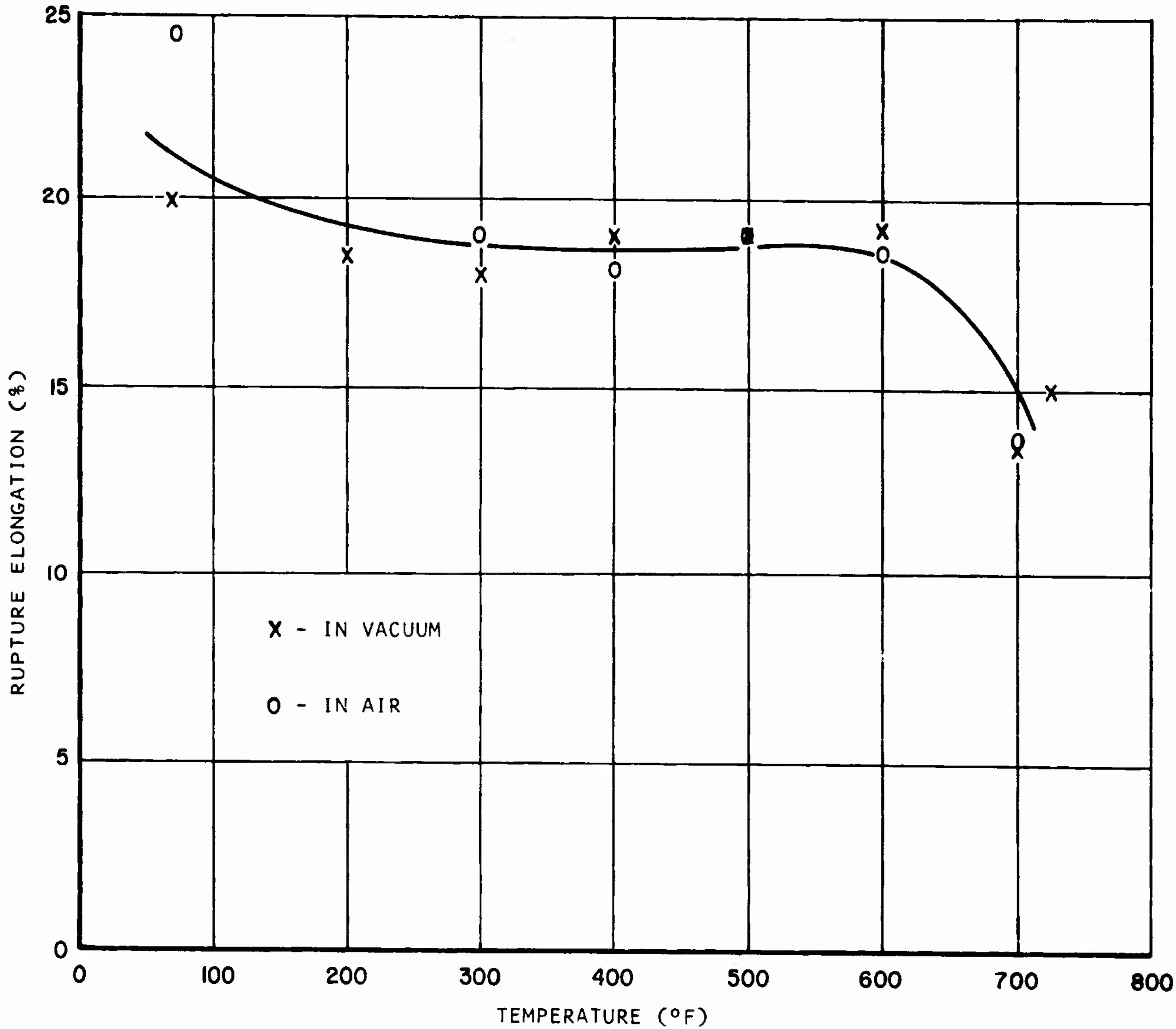

FIGURE 10. NOMEX FABRIC RUPTURE ELONGATION AS A FUNCTION OF TEMPERATURE.

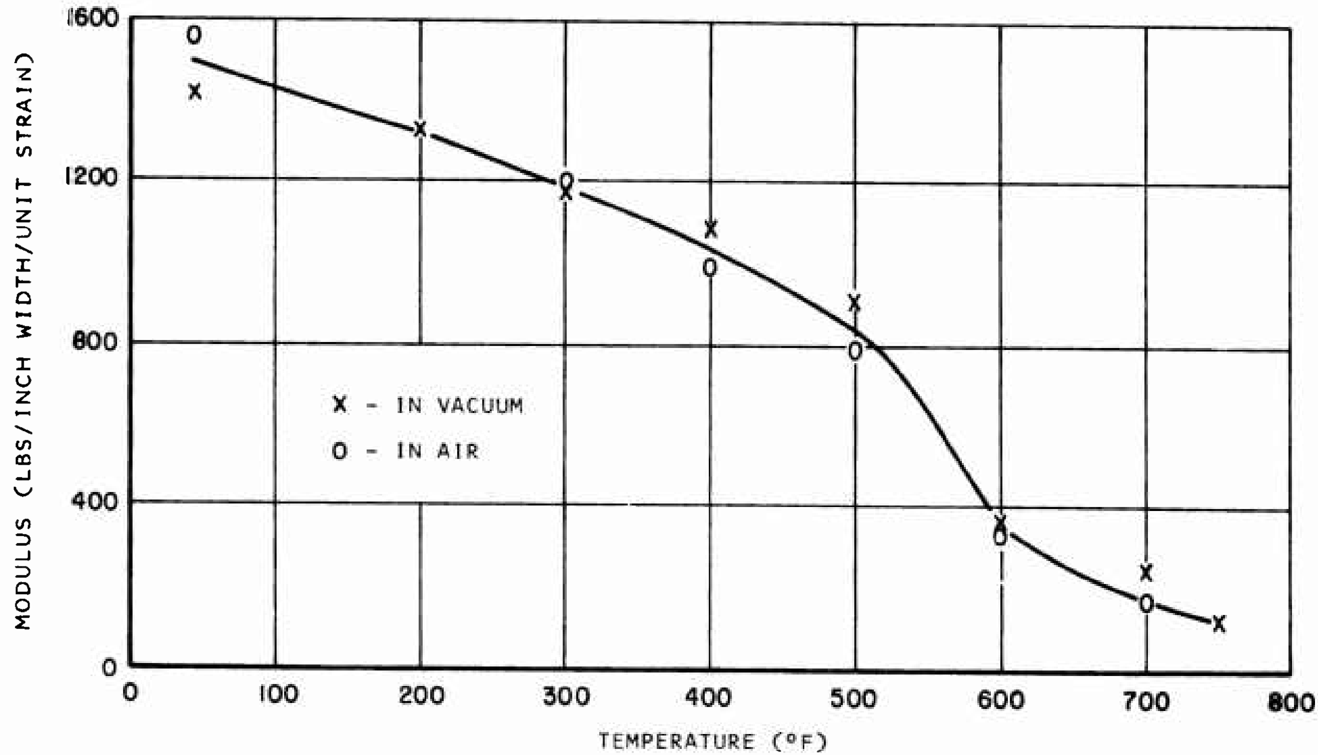

FIGURE 11. NOMEX FABRIC TENSILE MODULUS AS A FUNCTION OF TEMPERATURE.

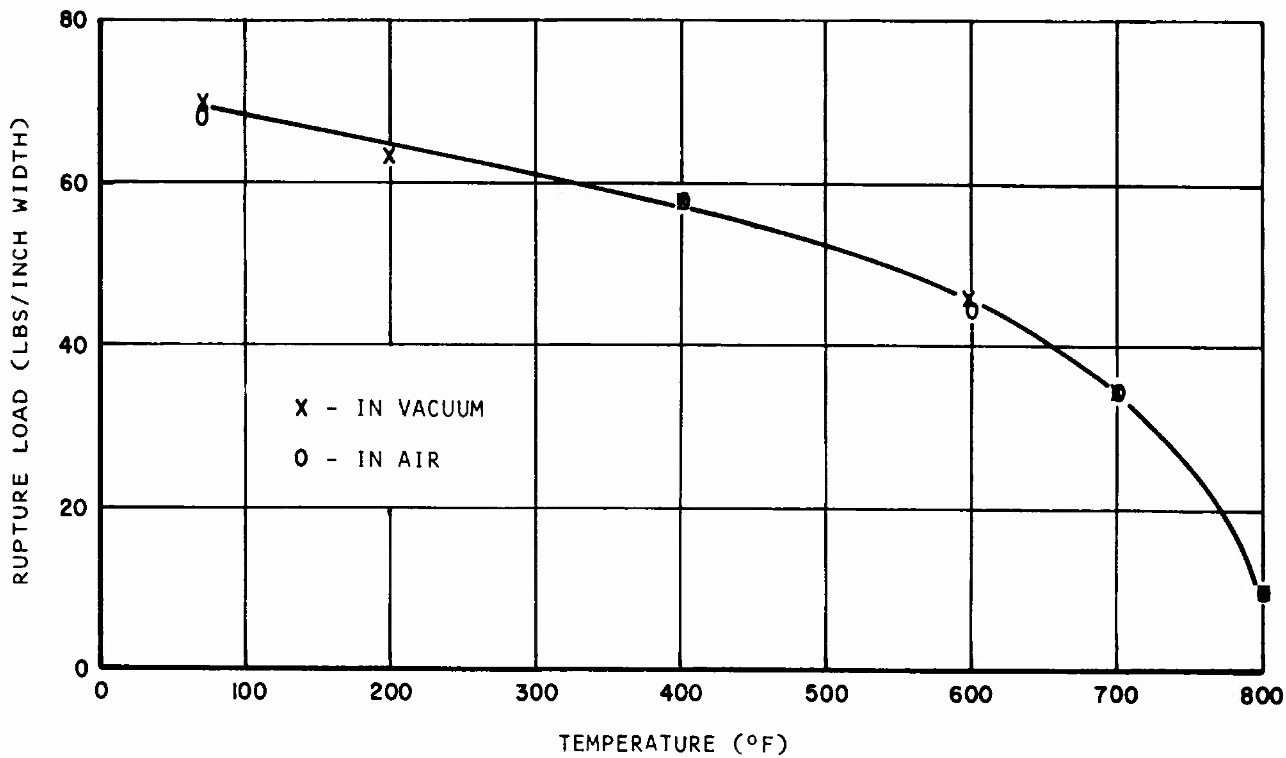

FIGURE 12. PBI FABRIC RUPTURE LOAD AS A FUNCTION OF TEMPERATURE

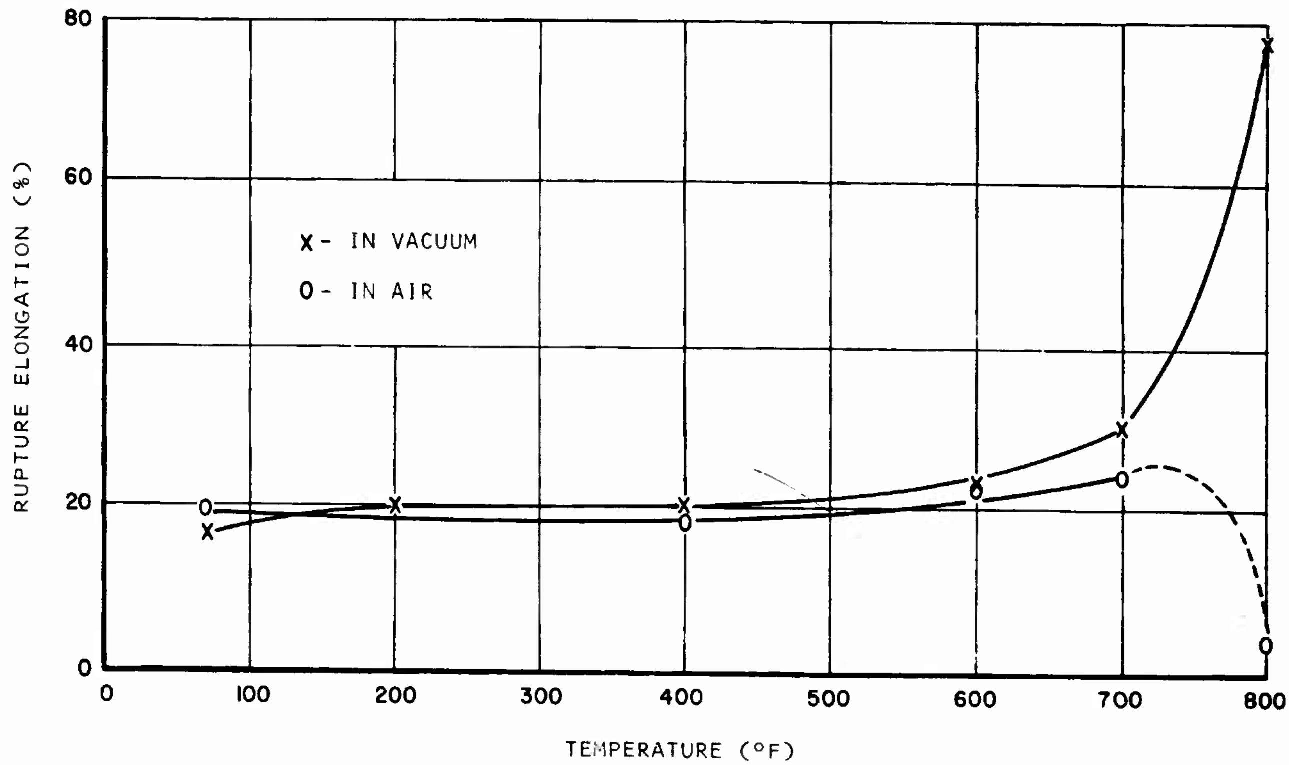

FIGURE 13. PBI FABRIC RUPTURE ELONGATION AS A FUNCTION OF TEMPERATURE

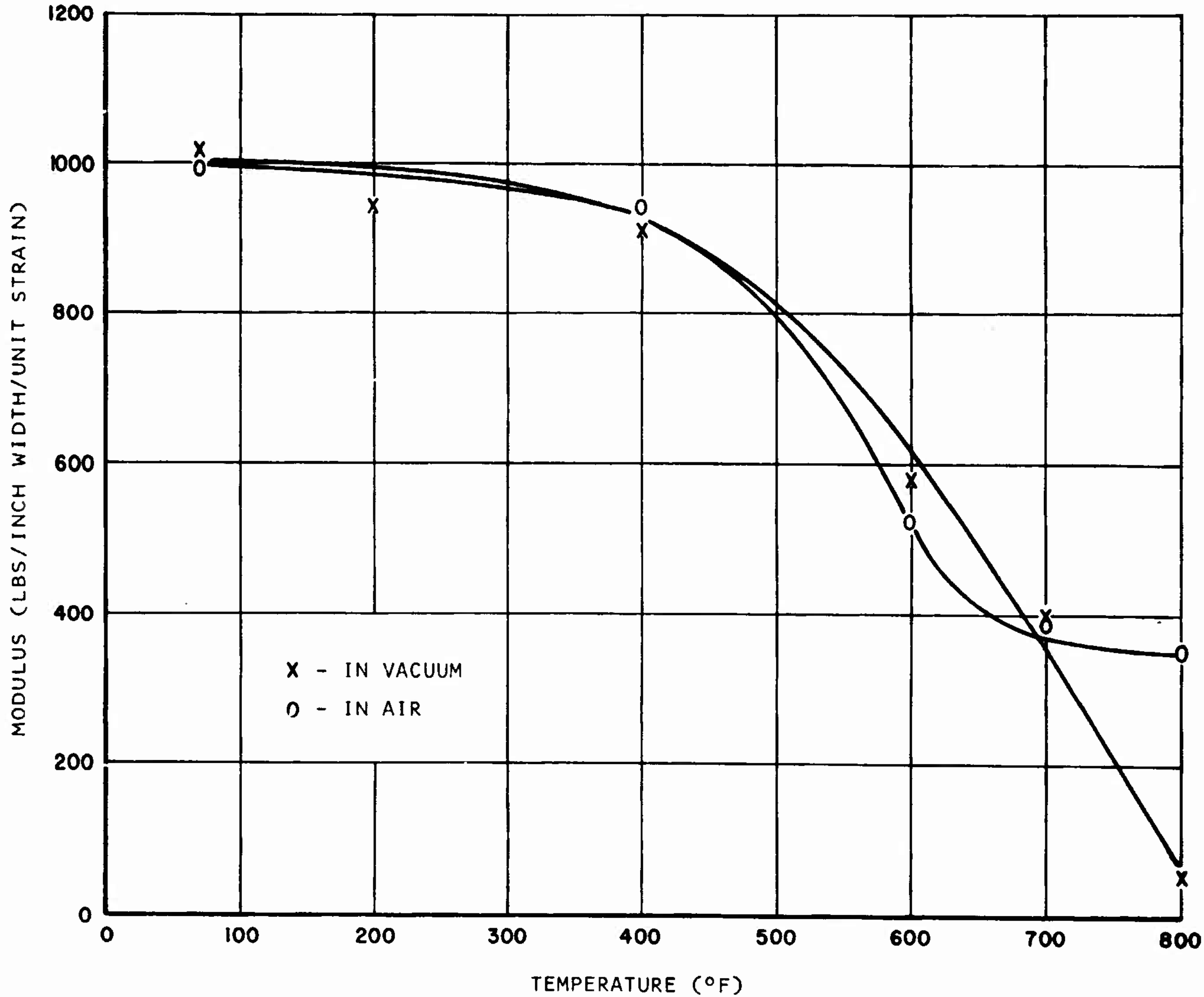

FIGURE 14. PBI FABRIC TENSILE MODULUS AS A FUNCTION OF TEMPERATURE

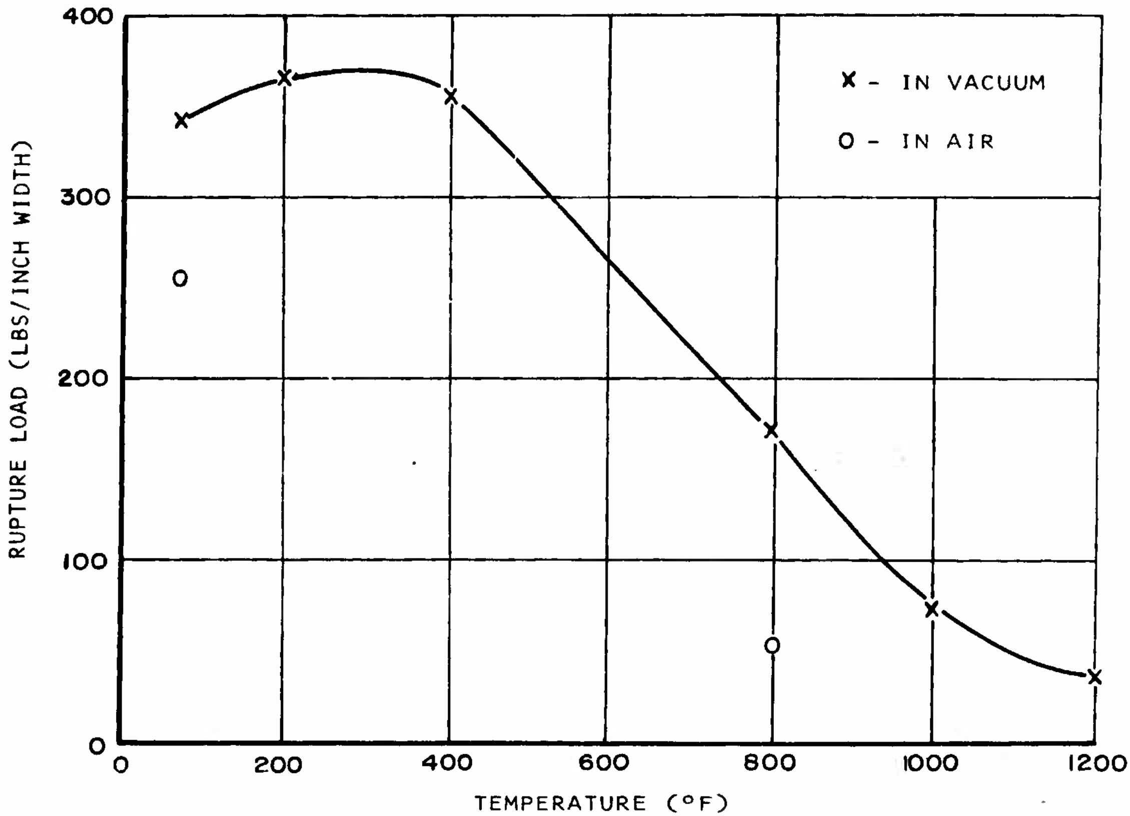

FIGURE 15. HEAT-CLEANED FIBERGLAS FABRIC RUPTURE LOAD AS A FUNCTION OF TEMPERATURE.

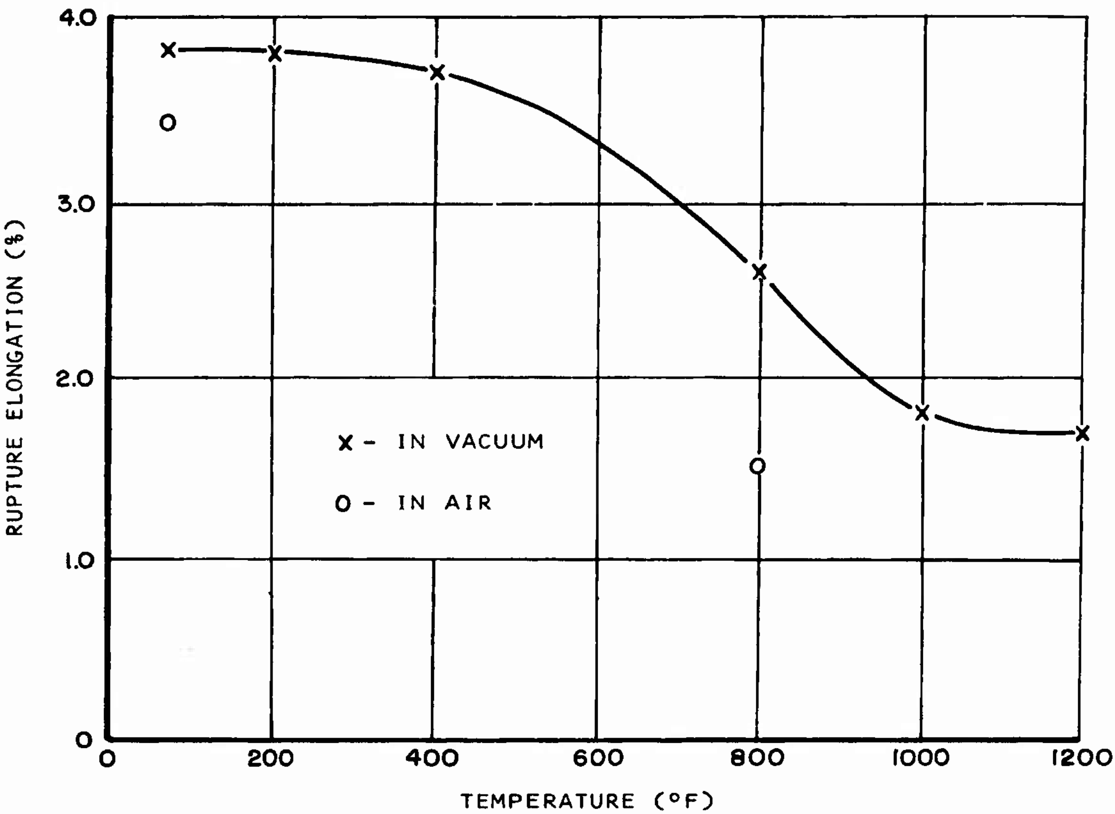

FIGURE 16. HEAT-CLEANED FIBERGLAS FABRIC RUPTURE ELONGATION AS A FUNCTION OF TEMPERATURE.

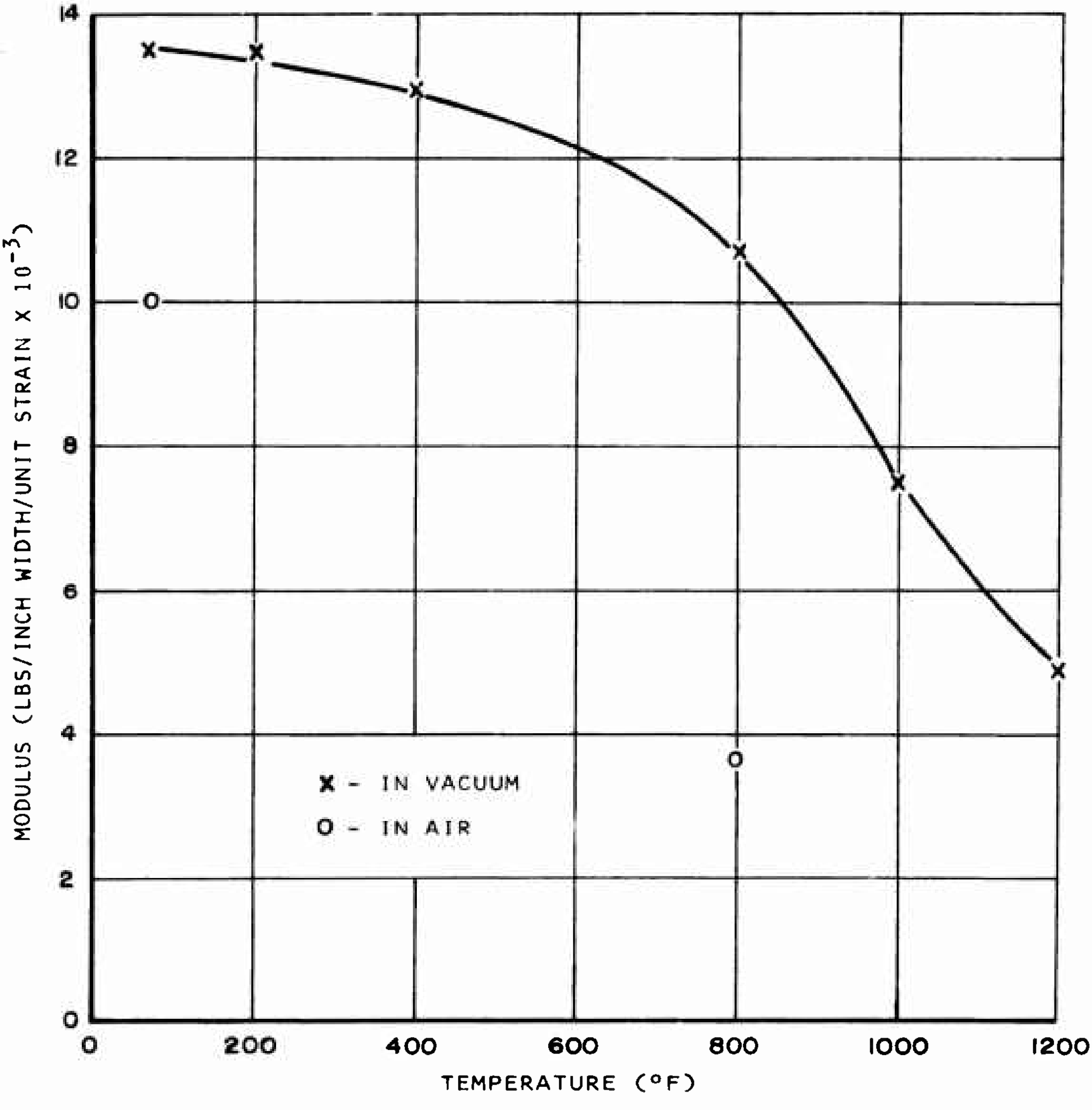

FIGURE 17. HEAT-CLEANED FIBERGLAS FABRIC TENSILE MODULUS AS A FUNCTION OF TEMPERATURE.

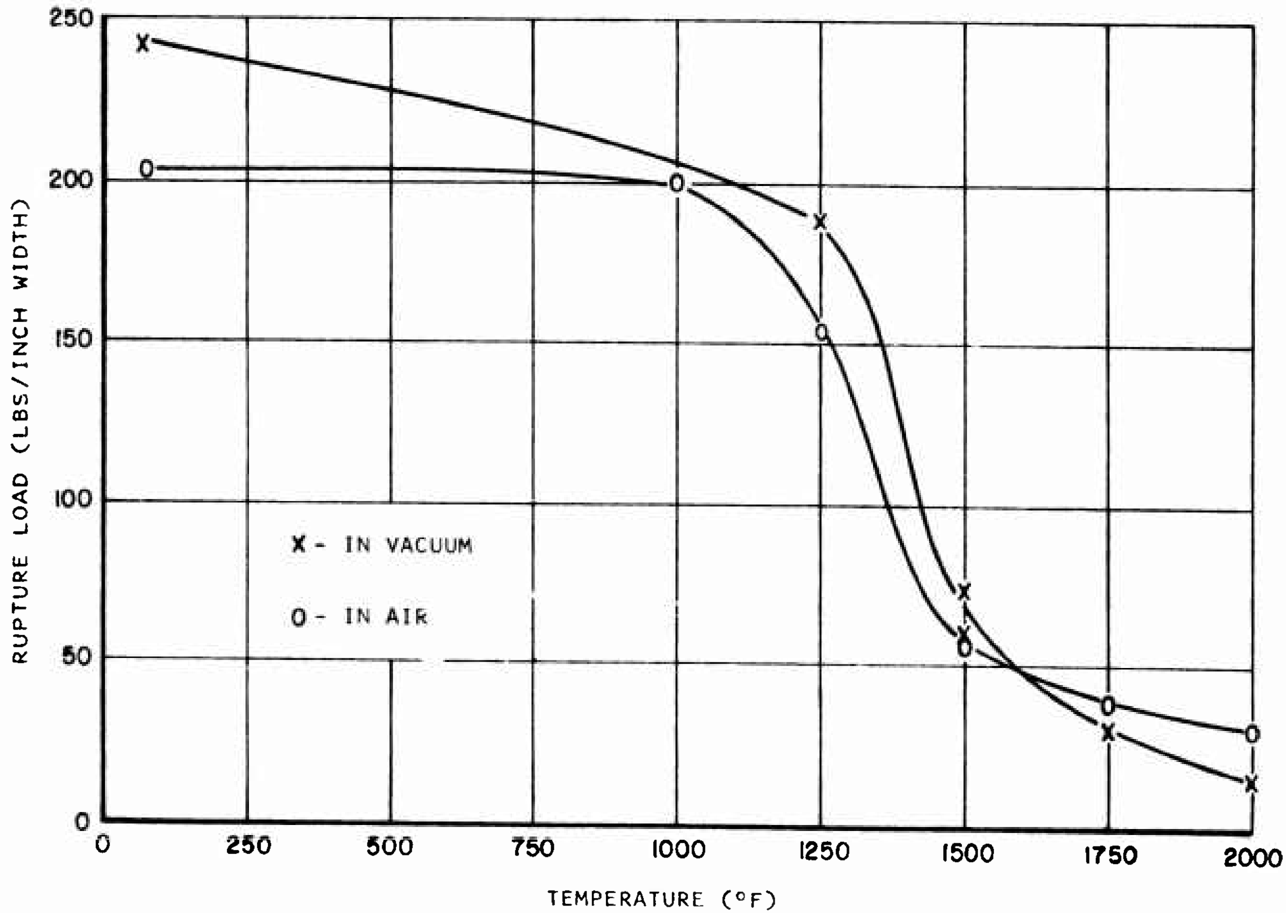

FIGURE 18. CHROMEL R METAL FABRIC RUPTURE LOAD AS A FUNCTION OF TEMPERATURE.

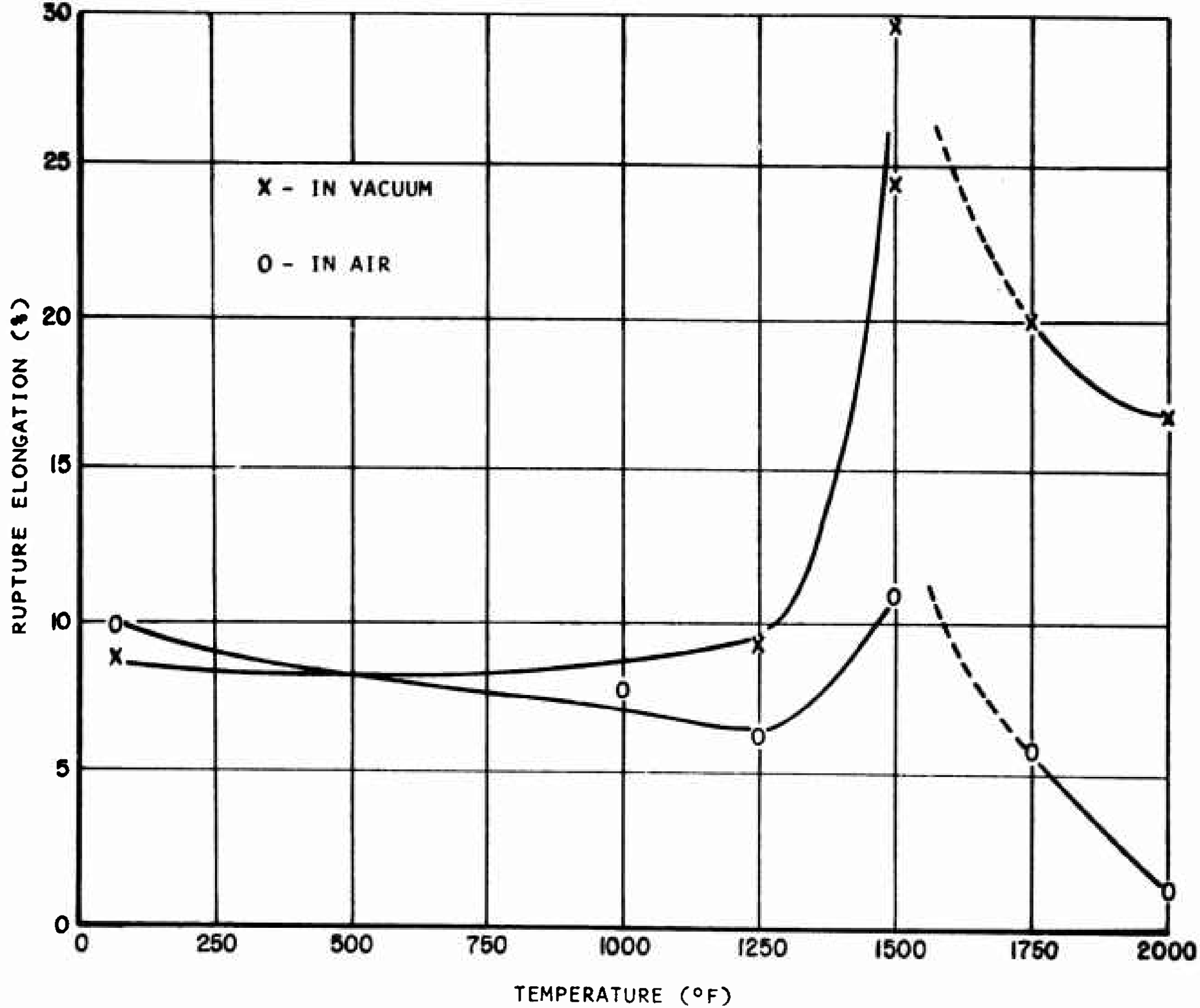

FIGURE 19. CHROMEL R METAL FABRIC RUPTURE ELONGATION AS A FUNCTION OF TEMPERATURE.

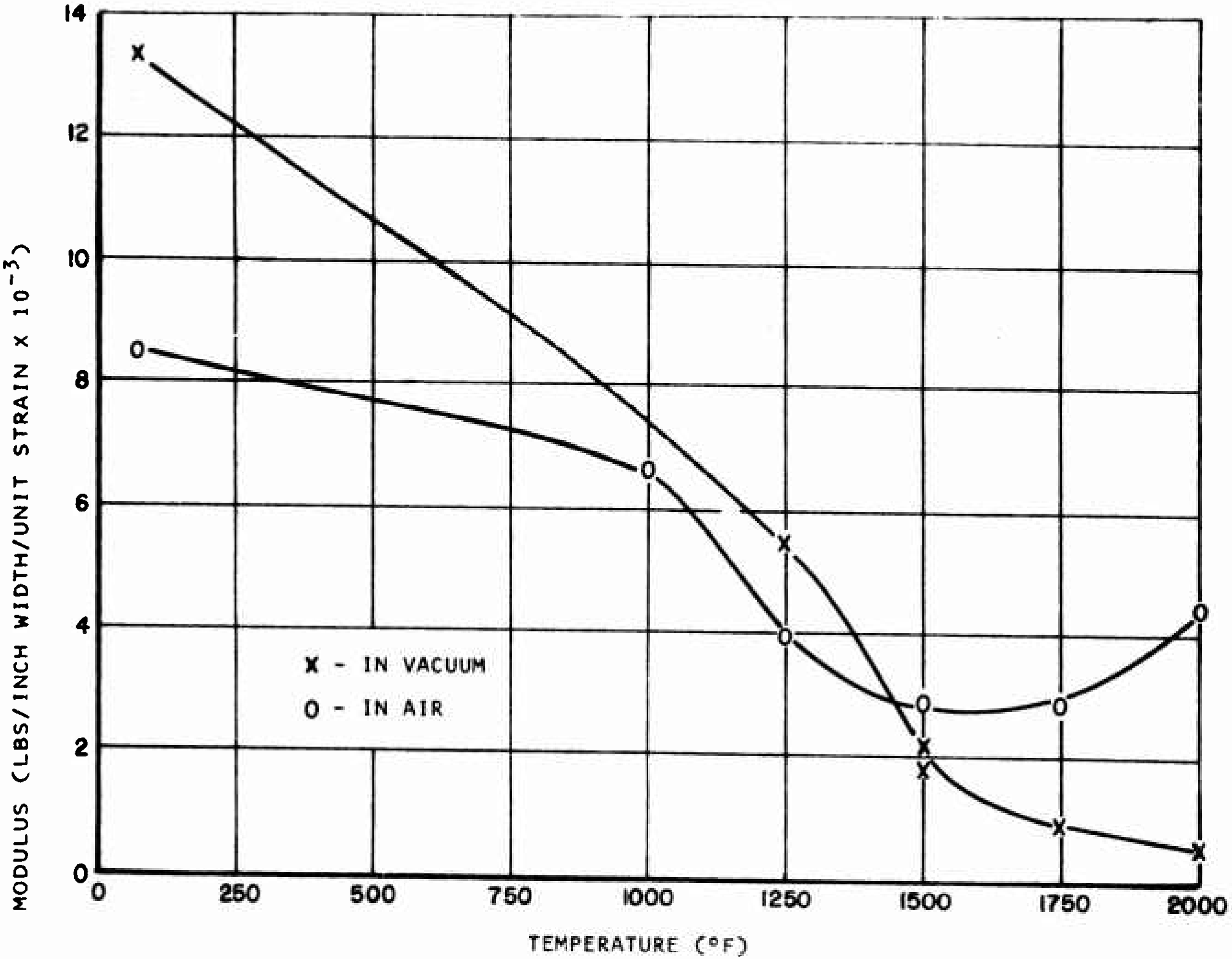

FIGURE 20. CHROMEL R METAL FABRIC TENSILE MODULUS AS A FUNCTION OF TEMPERATURE.

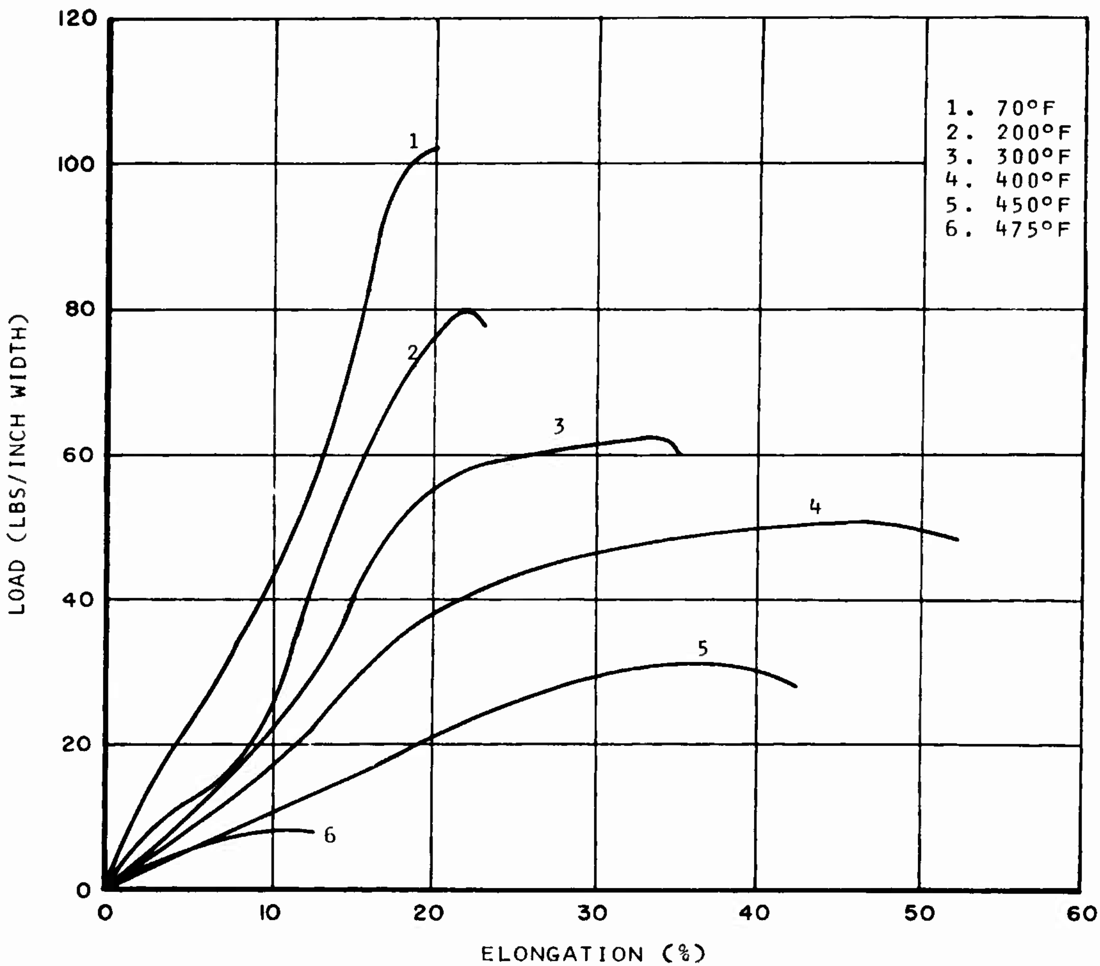

FIGURE 21. TYPICAL LOAD-ELONGATION DIAGRAMS OF NYLON FABRIC IN VACUUM.

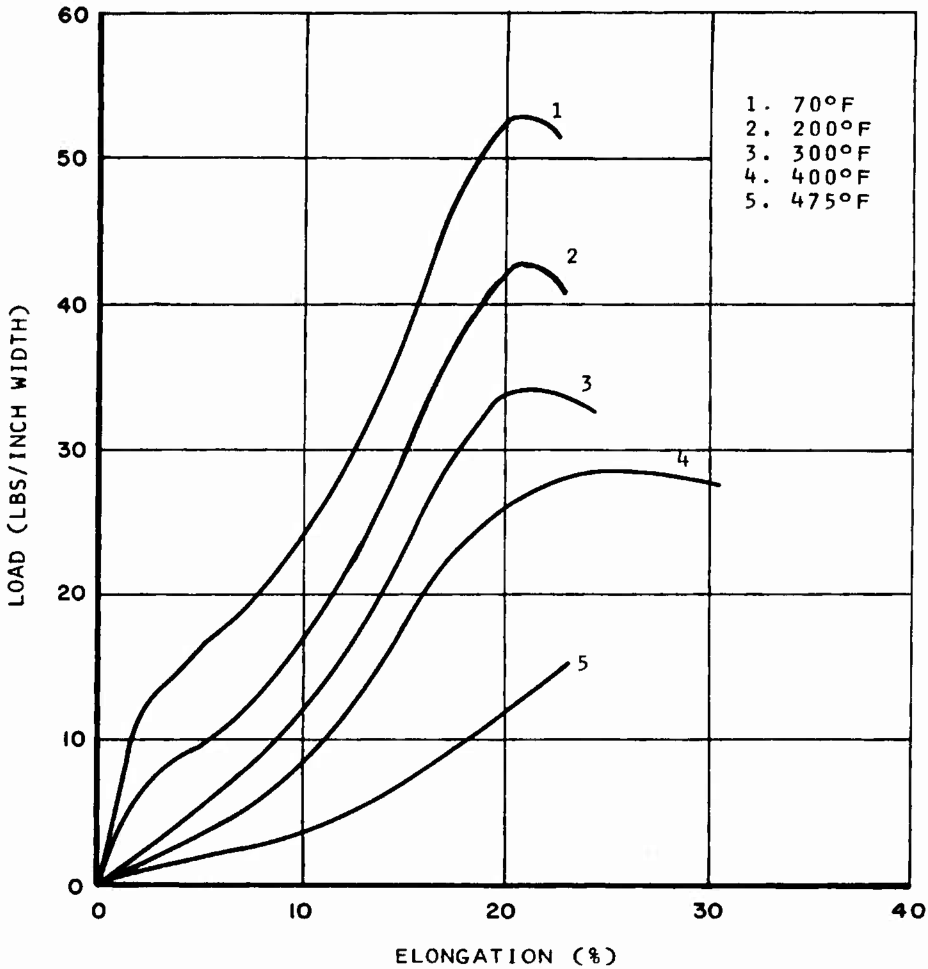

FIGURE 22. TYPICAL LOAD-ELONGATION DIAGRAMS OF DACRON FABRIC IN VACUUM.

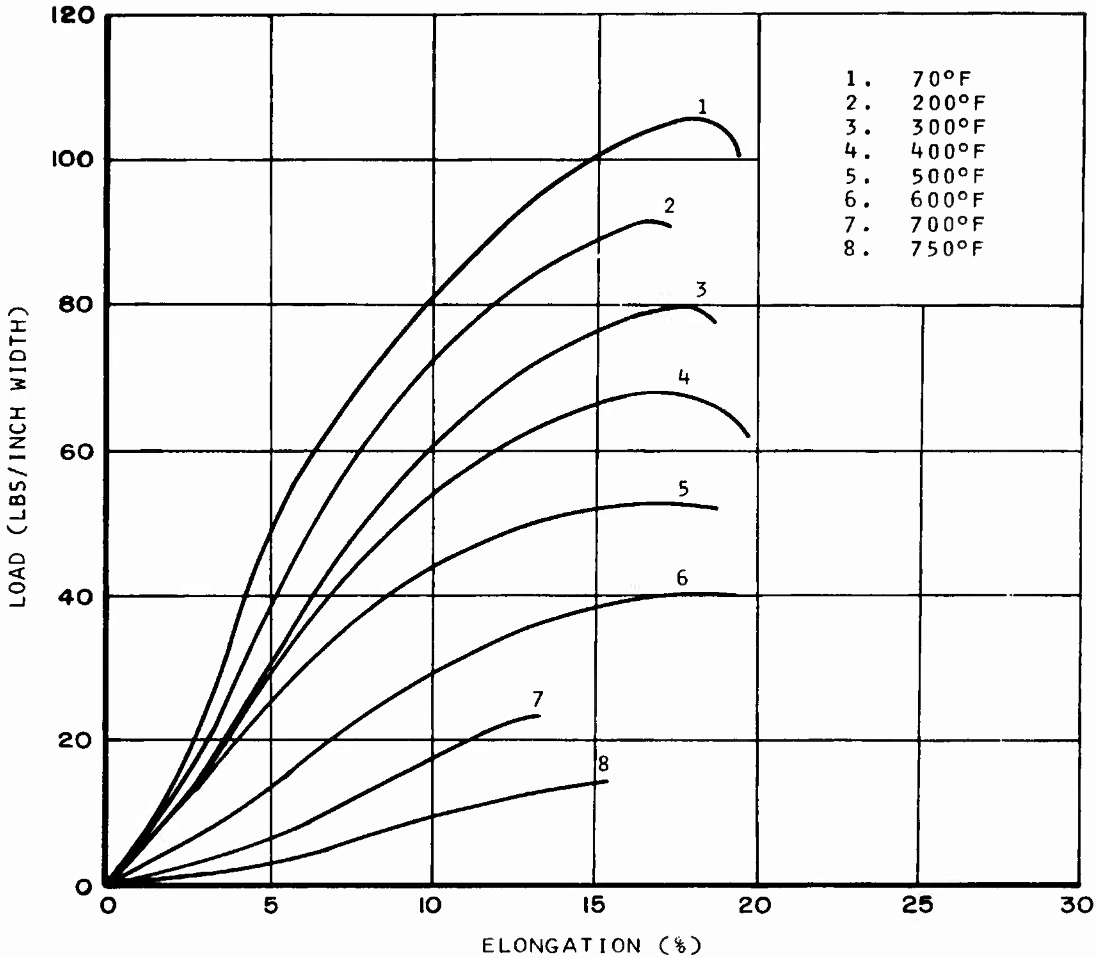

FIGURE 23. TYPICAL LOAD-ELONGATION DIAGRAMS OF NOMEX FABRIC IN VACUUM.

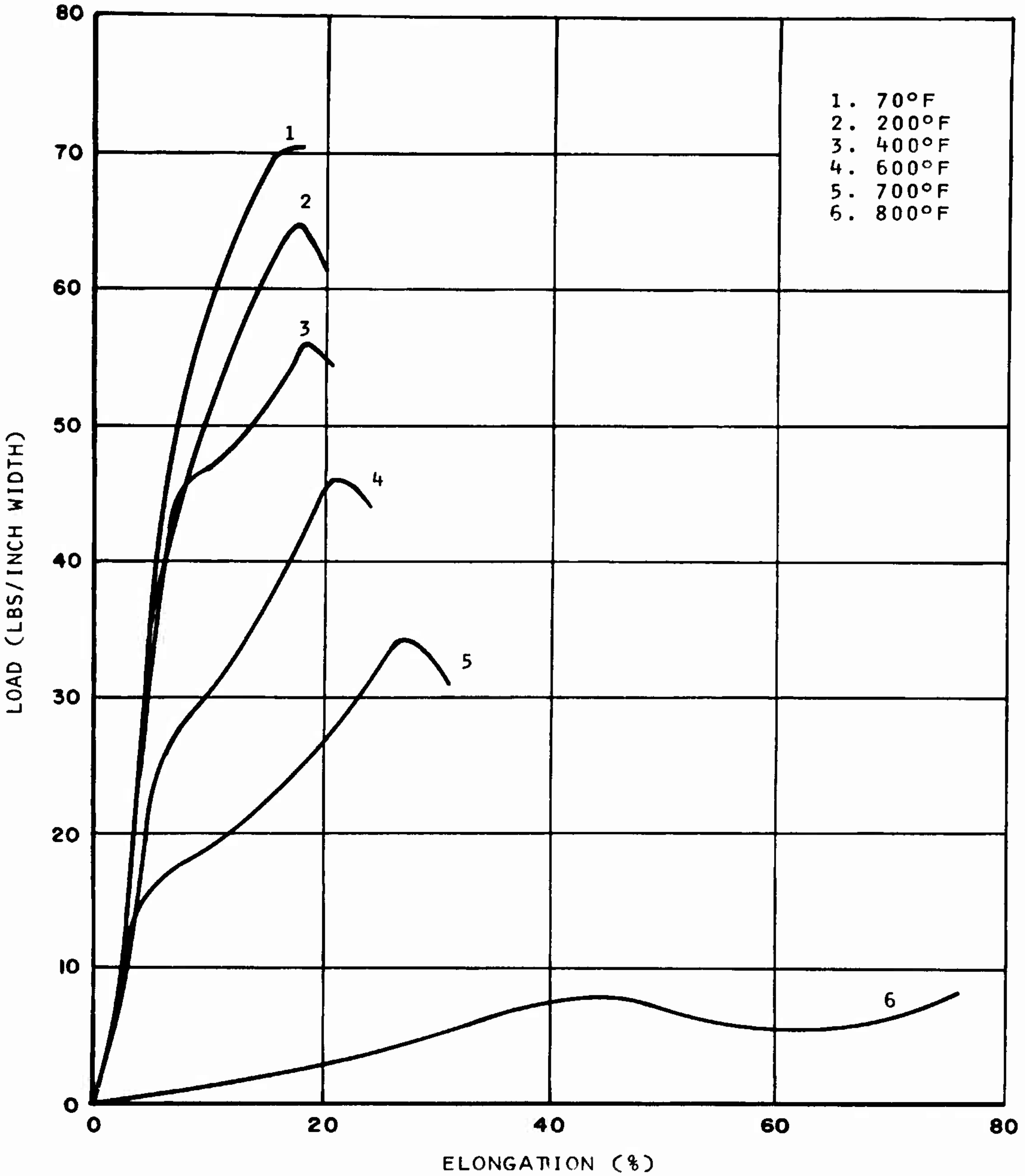

FIGURE 24. TYPICAL LOAD-ELONGATION DIAGRAMS OF PBI FABRIC IN VACUUM.

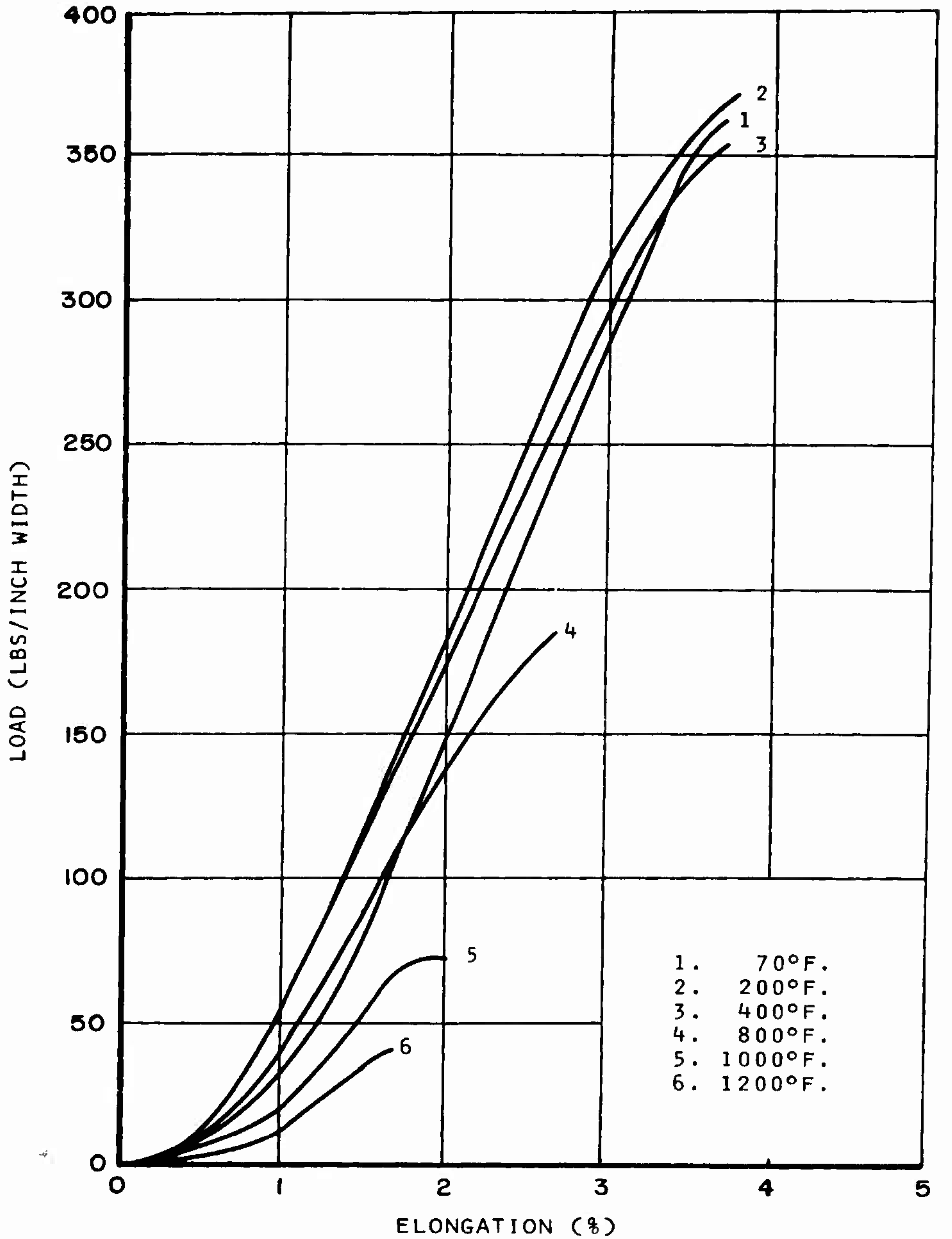

FIGURE 25. TYPICAL LOAD-ELONGATION DIAGRAMS OF HEAT-CLEANED FIBERGLAS FABRIC IN VACUUM.

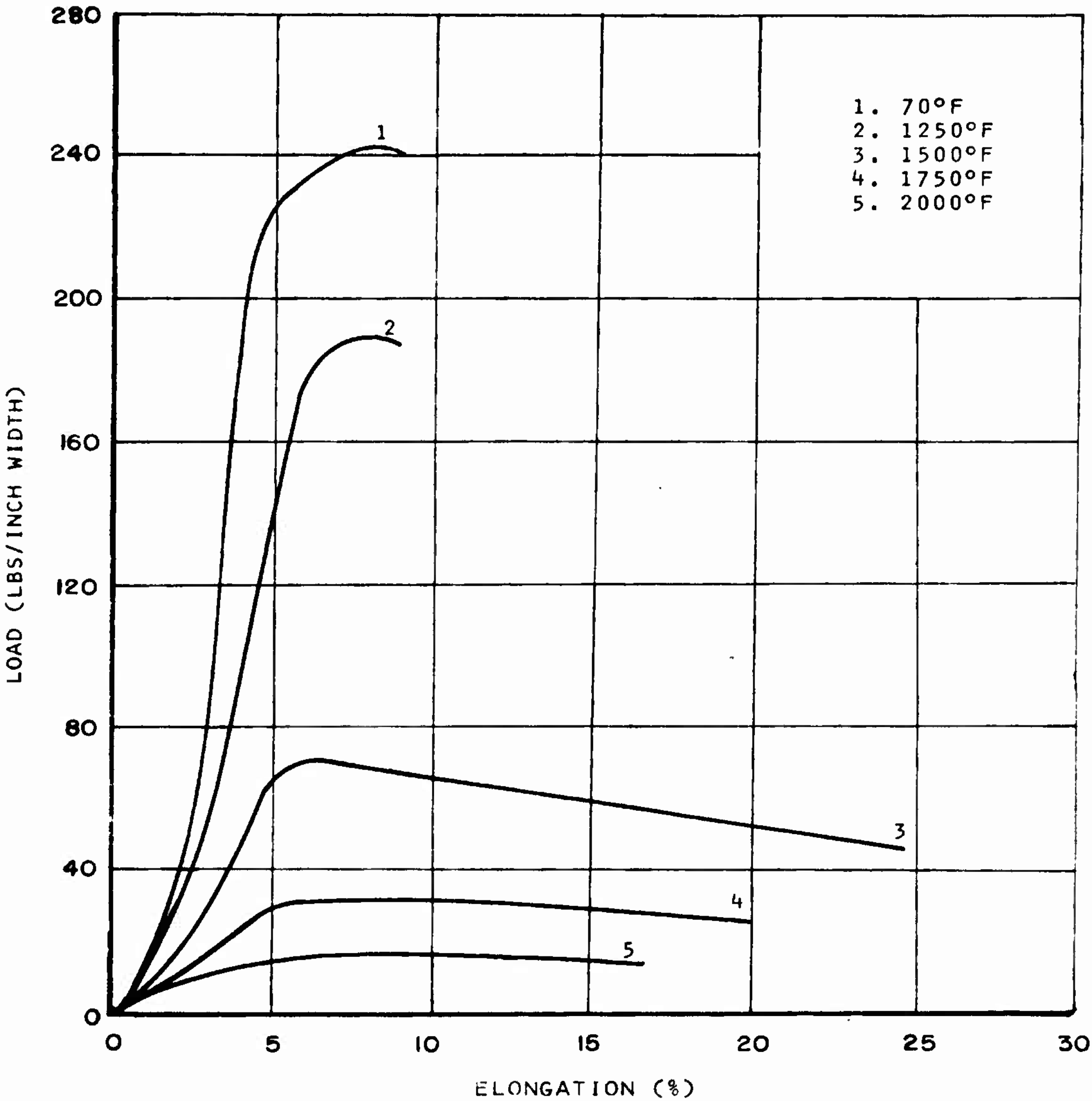

FIGURE 26. TYPICAL LOAD-ELONGATION DIAGRAMS OF CHROMEL R METAL FABRIC IN VACUUM.

The nylon, Dacron, Nomex, PBI, heat-cleaned Fiberglas and Chromel R metal fabrics evaluated in vacuum were also tensile tested at elevated temperatures in air. The results of the tests are given in Tables 13 through 18. The average properties of the fabrics at 70°F are also noted. This data is the same as that given previously in Tables 3 through 7 and 10. (It was obtained using a 3-inch gauge length, 3.0 inches per minute jaw speed–100% per minute strain rate–and flat, leather-lined jaws.)

The polymeric and glass fabrics were tested at elevated temperatures in a circulating hot-air oven* mounted in an Instron tensile tester, in the warp direction only, using one-inch wide ravelled-strip test specimens. A test specimen gauge length of 5 inches and jaw speed of 5.0 inches per minute (100% per minute strain rate) were used in evaluating the polymeric fabrics, and a gauge length of 5 inches and jaw speed of 0.5 inch per minute in evaluating the glass fabric. The test specimens were clamped in flat jaws lined with two layers of the same fabric as being tested.

The Chromel R metal fabric was tested in a clam-shell oven mounted in an Instron, using a 3.5-inch gauge length, 0.5-inch per minute jaw speed and serrated jaws lined with two layers of quartz fabric. A complete description of this equipment is given in Reference 3.

The temperature of the fabric test specimens in both chambers was determined with a thermocouple mounted immediately adjacent to the specimen midpoint. The test specimens were held at temperature for 15 minutes prior to testing; the temperature was maintained within approximately ±2% of the desired level during both the dwell time and test. A minimum of five test specimens were evaluated at each temperature.

Data is given for the heat-cleaned Fiberglas fabric for 70 and 800°F only (see Table 17) because of test specimen clamping difficulites encountered at temperatures between these two levels.

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*FRL® Environmental Test Chamber, manufactured by Custom Scientific Instruments, Inc., Kearny, New Jersey.

TABLE 13

TENSILE PROPERTIES OF NYLON FABRIC IN AIR

Specimen Temp (°F)	Shrinkage (%)	Yield Elongation (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elongation (%)	Rupture Load (lbs/inch width)
70 (65% RH)						
Avg[1]	---	Indefinite		662	24.6	106
200	1.4	3.4	8.0	495	22.8	80.0
	1.4	2.9	7.5	568	22.1	79.5
	1.5	2.7	8.0	588	20.0	80.4
	1.2	2.2	7.0	633	20.6	81.5
	1.4	2.7	7.6	578	21.8	82.0
Avg[2]	1.4	2.8	7.6	572	21.5	80.7
300	2.0	Indefinite		465	26.8	57.6
	1.9			420	27.4	58.5
	1.6			452	20.0	60.0
	1.8			442	24.5	60.5
	1.9			372	23.9	61.3
Avg[2]	1.8			430	24.5	59.6
400	3.5	6.7	9.0	153	18.0	21.0
	3.5	6.4	9.0	160	18.0	22.0
	3.4	6.5	9.5	160	17.5	21.0
	3.9	6.3	8.8	158	16.1	18.5
	3.2	5.7	8.0	159	16.7	21.0
Avg[2]	3.5	6.3	8.9	158	17.3	20.7
450	7.0	Indefinite		Indefinite	5.2	2.5
	5.5				4.2	2.0

1. 3-inch gauge length, 3.0-inches per minute jaw speed; flat, leather-lined jaws.
2. 5-inch gauge length, 5.0-inches per minute jaw speed; flat jaws lined with two layers of nylon fabric.

TABLE 14

TENSILE PROPERTIES OF DACRON FABRIC IN AIR

Specimen Temp (°F)	Shrinkage (%)	Yield Elongation (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elongation (%)	Rupture Load (lbs/inch width)
70 (65% RH)						
Avg[1]	---	2.3	12.2	715	22.6	55.2
200	0.0	1.9	7.4	518	21.1	45.6
	0.0	2.0	8.0	505	20.0	48.0
	0.4	2.0	7.2	467	19.4	43.7
	0.4	2.0	7.5	493	20.6	46.7
	0.0	2.1	8.0	503	21.8	48.6
Avg[2]	0.2	2.0	7.6	497	20.6	46.5
300	0.0	Indefinite		234	21.1	33.4
	0.0			237	21.5	34.6
	0.0			263	20.1	32.4
	0.0			282	18.8	35.0
	0.0			292	19.3	35.9
Avg[2]	0.0			262	20.2	34.3

1. 3-inch gauge length, 3.0-inches per minute jaw speed; flat, tape-lined jaws.
2. 5-inch gauge length, 5.0-inches per minute jaw speed flat jaws lined with two layers of Dacron fabric.

TABLE 14 (Cont.)

TENSILE PROPERTIES OF DACRON FABRIC IN AIR

Specimen Temp (°F)	Shrinkage (%)	Yield Elongation (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elongation (%)	Rupture Load (lbs/inch width)
400	0.0	17.9	23.0	206	28.0	28.8
	0.0	17.4	24.4	223	25.9	29.0
	0.0	17.6	23.7	187	22.4	25.5
	0.0	17.7	22.5	209	26.8	28.0
	0.0	17.7	23.0	205	28.5	28.3
Avg[1]	0.0	17.7	23.3	206	26.3	27.9
450	2.8	21.4	19	147	39.6	25.0
	3.4	21.8	16	100	31.6	20.0
	4.5	21.6	19	152	36.3	24.0
	3.5	21.9	18	138	32.4	22.0
	2.2	21.0	18	142	34.0	22.5
	3.2	21.4	18	144	36.2	24.0
Avg[1]	3.3	21.5	18	137	35.0	22.9
500	melts					

1. 5-inch gauge length, 5.0-inches per minute jaw speed, flat jaws lined with two layers of Dacron fabric.

TABLE 15

TENSILE PROPERTIES OF NOMEX FABRIC IN AIR

Specimen Temp (°F)	Shrinkage (%)	Yield Elongation (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elongation (%)	Rupture Load (lbs/inch width)
70 (65% RH)						
Avg[1]	---	Indefinite		1570	24.6	104
300	0.0	4.0	29	1160	17.4	80.0
	0.0	3.8	28	1180	19.4	84.5
	0.0	3.6	28	1300	18.8	85.0
	0.0	4.4	29	1140	19.8	82.3
	0.0	4.2	28	1230	20.3	85.8
Avg[2]	0.0	4.0	28	1200	19.1	83.5
400	0.0	4.0	24	1020	18.8	65.5
	0.2	4.0	23	970	19.0	67.0
	0.3	4.2	24	1020	18.5	68.3
	0.4	3.8	23	1120	19.0	68.5
	0.8	4.1	23	850	17.7	68.5
Avg[2]	0.3	4.0	23	1000	18.6	67.6

1. 3-inch gauge length, 3.0-inches per minute jaw speed; flat, leather-lined jaws.
2. 5-inch gauge length, 5.0-inches per minute jaw speed; flat jaws lined with two layers of Nomex fabric.

TABLE 15 (Cont.)

TENSILE PROPERTIES OF NOMEX FABRIC IN AIR

Specimen Temp (°F)	Shrinkage (%)	Yield Elongation (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elongation (%)	Rupture Load (lbs/inch width)
500	0.6	4.5	19	800	19.4	52.0
	1.1	4.0	19	787	19.8	52.6
	0.8	4.7	20	741	18.0	52.2
	0.3	4.5	20	820	18.2	50.0
	0.3	4.2	20	862	19.4	52.0
Avg[1]	0.6	4.4	20	802	19.0	51.8
600	2.0	4.2	12	389	17.9	39.4
	2.5	5.4	13	303	18.7	38.5
	2.8	5.0	12	342	20.0	39.0
	3.1	5.7	12	312	20.0	39.3
	2.2	4.2	12	376	17.0	38.4
Avg[1]	2.5	4.9	12	344	18.7	38.9
700	4.5	None		198	12.2	18.1
	4.2			192	12.6	20.0
	4.4			192	13.2	20.0
	4.8			203	15.0	21.8
	5.4			180	15.3	20.6
Avg[1]	4.7			193	13.7	20.1

1. 5-inch gauge length, 5.0-inches per minute jaw speed; flat jaws lined with two layers of Nomex fabric.

TABLE 16

TENSILE PROPERTIES OF PBI FABRIC IN AIR

Specimen Temp (°F)	Shrinkage (%)	Yield Elongation (%)	Yield Load (lbs/inch)	Modulus (lbs/inch)	Rupture Elongation (%)	Rupture Load (lbs/inch width)
70 (65% RH)						
Avg[1]	---	7.9	56	1000	19.4	68.3
400	0.8	7.7	44	935	18.4	57.6
	0.4	7.2	43	990	16.5	55.0
	1.0	7.2	43	952	18.2	57.5
	0.6	7.4	43	901	18.6	56.0
	1.0	7.5	44	943	19.2	57.8
Avg[2]	0.7	7.4	43	944	18.2	56.8
600	0.6	6.8	27	549	21.1	44.8
	0.6	6.4	26	524	22.4	44.3
	1.4	7.5	26	510	23.2	44.0
	1.4	6.7	26	529	23.5	46.0
	2.1	8.0	26	495	22.9	44.0
Avg[2]	1.2	7.1	26	521	22.6	44.6
700	---	5.6	16.7	386	23.2	34.6
	---	5.7	17.4	385	23.5	34.0
	---	6.0	17.4	382	23.0	33.9
	3.0	7.1	17.8	368	21.8	32.0
	1.3	6.2	18.5	384	18.9	30.5
Avg[2]	---	6.1	17.6	381	22.1	33.0
800[2]	4.5	---	---	379	3.70	10
	4.8	---	---	372	3.80	11

1. 3-inch gauge length, 3.0-inches per minute jaw speed; flat, leather-lined jaws.
2. 5-inch gauge length, 5.0-inches per minute jaw speed; flat jaws lined with two layers of PBI fabric.

TABLE 17

TENSILE PROPERTIES OF HEAT-CLEANED FIBERGLAS® FABRIC IN AIR

Specimen Temp (°F)	Shrinkage (%)	Yield Elongation (%)	Yield Load (lbs/inch)	Modulus (lbs/inch x 10^{-3})	Rupture Elongation (%)	Rupture Load (lbs/inch width)
70						
Avg[1]	---		None	10.0	3.4	256
800	---		None	5.6	1.8	59
				3.1	1.6	47
				3.1	1.5	55
				3.2	1.5	58
				3.1	1.3	46
Avg[2]				3.6	1.5	53

1. 3-inch gauge length, 3.0-inches per minute jaw speed; flat, tape-lined jaws.
2. 5-inch gauge length, 0.5-inch per minute jaw speed; flat jaws lined with two layers of Fiberglas® fabric.

TABLE 18

TENSILE PROPERTIES OF CHROMEL R METAL FABRIC IN AIR[1]

Specimen Temp (°F)	Shrinkage (%)	Yield Elongation (%)	Yield Load (lbs/inch)	Modulus (lbs/inch x 10^{-3})	Rupture Elongation (%)	Rupture Load (lbs/inch width)
70 (65% RH)	---	4.2	176	8.5	9.8	204
1000	---	4.2	175	6.6	7.9	201
1250	---	4.0	147	3.9	6.2	153
1500	---	1.1	21	2.9	10.9	56.2
1750	---	Indefinite		2.9	5.8	37.9
2000	---	Indefinite		4.4	1.3	30.7

1. Average values taken from AFML-TR-65-118;
3.5-inch gauge length, 0.5-inch per minute jaw speed; serrated jaws lined with two layers of quartz fabric.

The value given in Table 18 for the tensile strength of the Chromel R fabric at 70°F is considerably lower than that given in Table 10. There are several possible reasons for this difference: (1) The two sets of data were not obtained from the same piece of fabric. Although the construction details of both fabrics were identical, when evaluated using the same jaw-clamping procedure the fabric used in obtaining the data at elevated temperatures in air exhibited a tensile strength in the warp direction of 226 lbs per inch as opposed to 243 lbs per inch for the fabric tested in vacuum. (2) The data in Table 10 was obtained using flat, leather-lined jaws and a 100% per minute strain rate while that in Table 18 was obtained using quartz-fabric lined, serrated jaws and a strain rate of 14.3% per minute. Somewhat lower rupture loads are obtained with quartz-fabric lined, serrated jaws than with leather-lined Instron jaws.

To facilitate comparisons between data obtained in air and vacuum, the results given in Tables 13-18 are also plotted in Figures 3 through 20. As shown in Figure 3 the strength of the nylon fabric is approximately the same in air and vacuum at temperatures to 300°F. However, the fabric strength at 400 and 450°F is much greater in vacuum than in air. The fabric rupture elongation is approximately the same in vacuum and air to 200°F and much higher in vacuum at higher temperatures (see Figure 4). At 400°F the fabric elongation is 17.3% in air and 52.2% in vacuum. The modulus of the fabric is approximately the same in air and vacuum throughout the temperature range (see Figure 5).

As shown in Figure 6, the tensile strength of the Dacron fabric is roughly the same in air and vacuum to about 400°F and approximately 50% greater in air than in vacuum at 475°F. The rupture elongation of the fabric is moderateiy greater in vacuum at the elevated temperatures (see Figure 7). The modulus is approximately the same in both environments throughout the temperature range (see Figure 8).

As shown in Figures 9, 10, and 11, the tensile properties of the Nomex fabric are approximately the same in air and vacuum throughout the temperature range over which the material was evaluated.

The strength of the PBI fabric, Figure 12, is the same in vacuum and air at ambient and elevated temperatures. The rupture elongation of the fabric is the same in air and vacuum to about 700°F. However, at 800°F the elongation is 3.8% in air and 78% in vacuum (see Figure 13). The fabric modulus is also approximately the same in air and vacuum to 700°F; the modulus in air is about 7 times the value in vacuum at 800°F.

Although data on the heat-cleaned Fiberglas fabric is only available for 70 and 800°F in air, it appears that the tensile strength, rupture elongation, and modulus of the fabric are considerably larger in vacuum than in air at ambient and elevated temperatures (see Figures 15-17,

As shown in Figures 18, 19, and 20, it appears that when the differences in fabric properties at 70°F are taken into account, the tensile properties of the Chromel R fabric are approximately the same in vacuum and air to about 1250°F. At 1500°F the fabric exhibits approximately the same percent strength retention in both environments but considerably more elongation in vacuum. However, at 1750 to 2000°F the tensile strength and modulus of the fabric are smaller and the rupture elongation many times larger in vacuum.

SECTION IV

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13 ABSTRACT

The tensile properties of fabric woven from nylon, Dacron, Nomex, polybenzimidazole, graphite, Fiberglas and Chromel R were determined in vacuum at 70°F after vacuum exposures of 1 to 64 hours. The tensile properties of the fabrics were also determined at elevated temperatures in vacuum and the data compared to the fabric properties in air.

Vacuum exposures (to 1×10^{-6} torr) of 1 to 64 hours appear to have only a small effect on the tensile properties of polymeric fabrics. Over a broad temperature range polymeric and metal fabrics also exhibit roughly the same tensile properties in vacuum as in air. Fiberglas fabric exhibits up to 45% greater tensile strength in vacuum than in air.

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nylon, Dacron, Nomex, polybenzimidazole, graphite, Fiberglas, Chromel R, tensile properties, vacuum exposure, elevated temperatures						

INSTRUCTIONS

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